

University of Alberta

**Indoor Air Quality Study in Edmonton Public Schools, Elk Island Public Schools and
Elk Island Catholic Schools**

Ventilation and Comfort Parameters

by

Mary Onyewu Unobe



**A thesis submitted to the Faculty of Graduate Studies and Research in partial
fulfillment of the requirements for the degree of Master of Science**

in

Environmental Engineering

Department of Civil and Environmental Engineering

Edmonton, Alberta

Spring 2003



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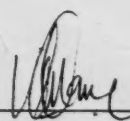
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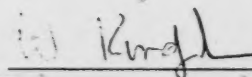
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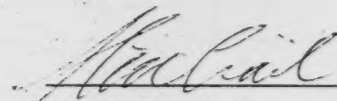
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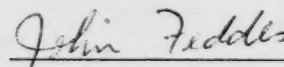
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Abstract

Capital Health Region encompasses the City of Edmonton and surrounding communities. This study undertook the air sampling of some IAQ parameters (carbon dioxide and carbon monoxide) and Comfort factors (temperature, relative humidity and ventilation) in schools drawn from Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools. Both engineering and physiological viewpoints of ventilation air were examined as they facilitate a rationalization between ventilation system performance and development of IAQ standards where human occupancy are concerned. Baseline levels of carbon dioxide, carbon monoxide, temperature, relative humidity and ventilation rates were established in 43 Schools. This was aided by Stratification with Random Sampling Experimental design. Baseline levels were comparable with both ASHRAE and Health Canada Standards. Statistical hypothesis testing (95% confidence level) indicated that indoor levels of the aforementioned parameters were higher than outdoor levels. The results of these tests suggested that ventilation effectiveness has impacts on indoor levels of CO₂.

Acknowledgements

Capital Health Authority, Edmonton Public School Board, Elk Island Public School Board, Elk Island Catholic School Board and Alberta Infrastructure are hereby acknowledged for their immense support towards the completion of this study.

The guidance of Dr Warren B. Kindzierski, Department of Civil and Environmental Engineering as well as Dr Prasad of the Department of Mathematics and Statistics, University of Alberta are gratefully acknowledged. Nick Chernuka provided the much needed technical support.

Finally, thanks goes to the Almighty God for his protection and provision through out this study.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Nature of the Problem

Indoor Air Quality (IAQ) is a global concern. In 1992, the World Bank designated Indoor Air Pollution in developing countries as one of the four most critical global environmental concerns (Hanson and Burroughs 1998). In advanced countries, indoor air quality issues have been the cause of many litigations and lawsuits due to the resultant health impacts United States Environmental Protection Agency (USEPA 1985). This led American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) to allocate 30% of it's total research budget to the study of IAQ in 1989 (Croome and Sherratt 1998).

IAQ and comfort in schools are of special concern. The United States Government's General Accounting office issued reports stating that one in five schools in the United States has IAQ problems (GAO 1995, 1996). Chang and Lee (1998) also established that discomfort in schools has considerable negative impact on learning, comprehension and motivation in students as well as reduces productivity in teachers.

According to Hanson and Burroughs (1998), poor IAQ and discomfort in schools have been attributed to deficiencies in ventilation systems. Ventilation in schools is critical to indoor air quality because children consume more volume of air per body weight as they are still developing physically and are therefore more likely to suffer the consequences of exposure to indoor pollutants. Indoor air quality issues related to ventilation systems are as a result of deficiencies in design, maintenance, operation, air balancing and occupancy related issues (Croome and Roberts 1998). Studies have

established that such deficiencies are responsible for 50% of IAQ generated problems and when corrected are capable of resolving 80% of these problems National Institute for Occupational Safety and Health (NIOSH 1993).

School facilities by design are densely populated so that maintaining a comfortable indoor environment is more difficult than in other facilities (Bayer 2000). Even though outdoor air required for occupant comfort is specified in building codes, it is not enforceable when ventilation systems are operational (Palmiter et al. 1993).

1.2 Study Overview

Capital Health Authority is one of the largest integrated comprehensive health service organizations in Canada. Its region encompasses the City of Edmonton and surrounding communities. In schools under Capital Health Region, there has been no record of any prevalent health effects resulting from poor IAQ. However, Capital Health Authority initiated a study with an overall objective of obtaining baseline data for ventilation rates, mould, carbon dioxide, carbon monoxide, temperature and relative humidity levels in schools drawn from Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.

In order to achieve this overall objective, the study was divided into three components. This thesis is the second component carried out in schools of Capital Health Region to establish baseline data for targeted IAQ parameters and comfort factors. The first component was the study of mould while the third component was the examination of mould, ventilation and comfort parameter relationships.

1.3 Objectives

The following objectives were addressed in this study to establish baseline levels of air quality parameters and comfort factors in schools in Capital Health Region:

- To describe experimental design processes and procedures for data collection.
- To describe indoor air quality parameters (carbon dioxide and carbon monoxide).
- To describe comfort factors (temperature, relative humidity and airflow or ventilation).

CHAPTER TWO

2.0 LITERATURE REVIEW

The sole purpose of a school facility is to foster a learning environment, which is greatly enhanced if it is free of contaminants and comfortable. In schools investigated in this study, the focus was on classrooms only. Spaces such as gymnasium, washrooms, science rooms, etc. were excluded. Occupation of classrooms was mandatory in order to establish the effect of IAQ parameters and comfort factors. Classrooms and space have the same meaning and were therefore used interchangeably through out this thesis.

2.1 Historical Development of IAQ, Ventilation and Comfort

Indoor air quality problems are steeped in antiquity and can be traced back to the 13th century (Hines et al. 1993). In 1273, fumes from burning of coal were considered dangerous to health therefore Parliament petitioned the King of England to stop the burning of coal altogether (Hansen and Burroughs 1998).

Initially, comfort was the main consideration of IAQ. The Roman baths were designed to control the volume of water, light, air and sound in any room through window placement, plumbing and furnaces. By the 19th Century, building envelope and its orientation was linked to heating, ventilation and water distribution systems as architectural and engineering attempts to provide an acceptable indoor environment. Buildings were thus built spaciouly with self-contained ventilation systems designed to provide a closely controlled environment (Modera and Persily 1993).

The world energy crises in the 1970's had a tremendous impact on energy consumption. Energy conservation became the order of the day with the result that

building construction became smaller and well insulated. Ventilation systems were also controlled in order to reduce heat during non-hours. Consequently, there was increased reliance on mechanical ventilation to maintain indoor air quality and comfort (Hansen and Burroughs 1998).

There were several early theories surrounding the reason for discomfort. It was generally accepted that any discomfort of an excessively hot classroom was solely attributed to temperature. For more than 100 years after this, excess carbon dioxide from respiration in a crowded room was attributed as the cause of discomfort experienced (Hines et al. 1993). This was adequately addressed by Reid in 1848 when he wrote (Awbi 1991):

"Mental anxiety may perhaps be considered the most powerful enemy to duration of human life and next to it defective nutrient whether in quantity or quality. But after that no other cause at least in times appears to have afflicted so great an evil upon human race as defective ventilation."

2.2 Indoor Air Quality

A great deal of public attention is focused on indoor air quality issues in schools. Architects, environmental engineers and occupational hygienists have been challenged to address complaints of parents and teachers who associate ill health and discomfort with environmental conditions in classrooms. Thus indoor air quality has become the subject of many debates. Indoor air quality is an indicator of how well air satisfies three requirements for human occupancy namely: thermal acceptability, normal concentration of respiratory gases (oxygen and carbon dioxide) and suppression of other contaminants below levels that are deleterious or cause discomfort (Brooks and David 1992).

Both outdoor and indoor sources are contributing factors to these three requirements. Ultimately, the source of indoor air is from outdoors therefore certain characteristics of the outdoor air will be reflected indoors. For instance, the ambient air in Los Angeles is known for its photochemical smog and this is reflected in the conditions of buildings in such areas (Godish 1989).

Seasonal variations may also be reflected in the quality of the indoor air (Otson et al. 1992). Studies have shown that there are more significant amounts of mould spores indoors in the summer than in the winter (Otson and Meek 1990).

The impact of indoor environmental conditions such as noise, chemical and biological pollutants, lighting, temperature and relative humidity on IAQ in classrooms are numerous and well documented (Hanson and Burroughs 1998). The comfort temperature range of an individual is believed to be in the range of 20 to 26°C with relative humidity levels ranging from 30 to 50% (ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy Standard). Therefore, what constitutes an acceptable indoor air quality cannot be overlooked. As cited by ASHRAE Standard 62-1989 and ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality, air quality is:

"Air in which there are no known contaminants at harmful concentrations and with which a substantial majority (usually 80%) of the people exposed do not express dissatisfaction."

In educational institutions, the amount of air required to satisfy 80% of the occupants in a space vary from space to space depending on the intended usage of the space (Knight et al. 1986). For instance, the amount of outdoor airflow rate specified for gymnasiums is different from that specified for classrooms (ASHRAE Standard 62-2000, ventilation for

Acceptable Indoor Air Quality). Ventilation systems are designed to ensure that the required airflow rates are delivered to their respective spaces. This ensures that indoor air contaminants are maintained at acceptable levels and the majority (80%) of occupants in spaces are satisfied.

2.3 Parameters of Indoor Air Quality

2.3.1 Ventilation

Increased emphasis on energy conservation has given rise to a reduced rate of outdoor air supplied indoors. Consequently, indoor pollutant levels are on the increase due to recirculation of indoor air (Desrochers 1986). Bayer (2000) conducted a study of ventilation in schools and reported that schools with central Heating Ventilation and Air-conditioning (HVAC) systems have an average outdoor air delivery rate in the range of 7 to 15.4 m³/hr per person. In contrast, schools with unit ventilators reported an average outdoor air delivery rate in the range of 13 to 24.5 m³/hr per person. The higher ventilation rate also lowered average pollutant levels in the schools. Outdoor air or ventilation air is considered as (ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality):

"That portion of supply air which is outdoor air plus any recirculated air which has been treated for the purpose of maintaining acceptable indoor air quality".

As specified by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), the amount of outdoor air or ventilation air required to maintain an accepted indoor air quality is in the range of 25.5 to 34 m³/hr (15 to 20 cfm) (ASHRAE Standard 62-1989 and ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality respectively).

There are two views regarding ventilation air and a distinction must be made between them. The engineering view considers ventilation air as outdoor air (excluding indoor recirculated air) distributed to a space. It is also used as a basis for estimating design airflow rates for ventilation systems. From the physiological viewpoint, ventilation air refers to respired air in an occupied space (Woods 1986). Both concepts are important in maintaining a comfortable indoor environment as they facilitate a rationalization between ventilation system performance and development of standards where human occupancy is concerned (Robertson et al. 1985). The ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality was established on the basis of outdoor air supplied therefore ventilation rates used in this study consisted of only outdoor airflow rates with the exclusion of both return air and exhausted air from a space.

Ventilation is achieved through infiltration and natural ventilation as well as mechanical ventilation processes. Infiltration and natural ventilation are extremely effective in reducing the level of pollutant in spaces during short-term activities like cleaning (Hines et al. 1993). World Health Organization (WHO) reported that open doors and windows often increase the airflow rate in a space (Hines et al. 1993). Infiltration is considered to be air leakages through imperfections in building structure such as cracks, joints, refill panel and connections in the building envelope (Walsh et al. 1984). Natural ventilation on the other hand is the desired exchange of air through intentional opening in building envelope such as doors and windows (Hanson and Burroughs 1998).

Ventilations rates from natural and infiltration processes are often difficult to predict due to several associated variables (Hutcheon and Handegord 1985). Evidence

suggests that wind turbulence can cause sufficient variations in pressure differences which affect mixing in occupied spaces (Hines et al. 1993). Furthermore, placement and utilization of windows and doors significantly affect ventilation rates in occupied spaces (Croome and Roberts 1986). Natural ventilation was ignored in this study.

Through mechanical ventilation, air is directly supplied to a space through diffusers and air grilles placed at strategic locations on ceilings and walls. This is more efficient than natural ventilation because with the aid of fans, there is some measure of control over airflow to a space. Also, air increment and design conditions are not subject to the uncertainties of natural ventilation (Hanson and Burroughs 1998). Heating, Ventilation and Air Conditioning (HVAC) systems are the ventilation system of choice in residential buildings and particularly schools (ASHRAE 1982, Handbook of Applications).

2.3.2 Indoor Air Contaminants

More than 800 gases have been identified from outdoor sources (Goodfellow 1998, ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality). But most of them are unlikely to be present in sufficient concentrations indoors as to constitute a health hazard (Croome and Roberts 1981). The most common contaminants found indoors based on their frequency of occurrence at detectable levels are sulphur dioxide, carbon monoxide, ozone, nitrogen dioxide, nitric oxide and ammonia to mention a few (Calgary Health Services 1993, Health Canada 1995).

Air pollutants generated indoors include but are not limited to carbon dioxide, carbon monoxide, body odour and gases from building materials, furnishings, plants, etc. (Awbi 1991, Woods 1983). This study is targeted towards the investigation of carbon monoxide and carbon dioxide concentrations as indicators of indoor air quality.

2.3.2.1 Carbon monoxide

Carbon monoxide (CO) in classrooms is generated from both outdoors and indoor sources (Hines et al. 1993). Automobile exhaust is considered to be the primary source of outdoor carbon monoxide levels in the range of 0.05 to 0.92 mg/m³ (0.04 to 0.8 ppm) for rural areas and 57.5 mg/m³ (50 ppm) for urban areas (Health Canada 2000). The high urban carbon monoxide concentration indicates high traffic densities. Awbi (1991) reported that an average of 7.1×10^{-4} m³/s of CO is emitted per vehicle.

Indoor sources include tobacco smoke and combustion appliances. Tobacco smoke and indoor air quality is a subject that has generated much research over the years. In a single cigarette, CO is produced at a rate of 8×10^{-4} m³/s per cigarette (Hines et al. 1993). Although smoking in the school premises is usually prohibited and certain locations far from critical sources are provided for this purpose, deviations from such rules cannot be overlooked.

Combustion appliances have also been identified as a major contributor of indoor CO pollution. These include cooking appliances in home economics classes, gas heaters and furnace heating systems. The concentration of carbon monoxides gas introduced directly into a space depends on the space design, ventilation system and combustion efficiency (Apte and Traynor 1986).

Ventilation has been identified as an effective method of controlling indoor carbon monoxide levels (Croome and Roberts 1998). One method is the United States National Primary Ambient Air Quality Standards (USNAAQS), which require that carbon monoxide concentrations in outdoor air meet the requirements for acceptable indoor air quality. Based on reports by Croome and Roberts (1998), Apte and Traynor (1986), Traynor et al. (1981), when spaces are not vented, CO concentrations from furnace systems, gas cookers and space heaters tend to increase rapidly within the first hour then

reach a steady state level, which is maintained until the combustion equipment is turned off. It was not expected that high levels of CO would be observed during field sampling because schools were usually located away from dense traffic and indoor CO emissions are vented outside.

2.3.2.2 Carbon dioxide

The presence of carbon dioxide (CO₂) in ambient air is a natural occurrence. USEPA (1985) reported between 540 to 810 mg/m³ (300 to 450 ppm) as CO₂ in ambient air. Elevated levels above 810 mg/m³ are usually attributed to automobiles.

Indoor CO₂ emissions from gas burners and furnaces type ventilation systems are another source of indoor CO₂ concentrations in schools. But CO₂ produced as a by-product of metabolism has more impacts on indoor air quality (Canadian National Center for Occupational Health and Safety, GCOHS 1999). The average sedentary person produces approximately 5×10^{-6} m³/s of CO₂ through respiration, which increases with stronger activity levels (Awbi 1991, Dols and Persily 1993). A range of 1260 to 3600 mg/m³ (700 ppm to 2000 ppm) has been reported as indoor CO₂ concentrations (Health Canada 2000). Peak indoor concentrations can often exceed 5400 mg/m³ (3000 ppm) where there is operation of an unvented combustion appliance (Traynor et al. 1981b). The total CO₂ concentration within a space is increased above the CO₂ content in outdoor air depending on occupant density, outdoor airflow rate and efficiency of the ventilation system. Individually, these factors have little or no effect on indoor CO₂ concentration within a space (Bayer 2000).

The relationship between outdoor and indoor CO₂ levels has been used to evaluate the efficiency of ventilation systems. Hines et al. (1993) reported that indoor and outdoor CO₂ levels that maintained the same relationship through out the day indicate

that the ventilation air is adequate but suggests an imbalance in the ventilation system. If outdoor and indoor CO₂ levels were the same at the beginning of the day, a later increase in indoor CO₂ content indicates insufficient air exchange rate for the level of occupancy or activities at the time (Kern and Spoormaker 1976). This relationship could not be confirmed in this study due to a limited number of air samplers.

Indoor CO₂ concentration has been widely used as a measure of outdoor air supply since the later part of the 19th century (Hanson and Burroughs 1998). ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality sets the limit at 1800 mg/m³ (1000 ppm). Persily (1988) also emphasized using outdoor air as a reference for indoor CO₂ levels. He established a differential of 1170 mg/m³ (650 ppm) over the ASHRAE 62-2000 limit as a more appropriate target due to potential elevation and fluctuation of CO₂ concentration outdoors. An indoor CO₂ concentration above 1800 mg/m³ (1000 ppm) does not constitute a danger to occupants. Rather it suggests the presence of other contaminants at undesirable levels (Woods 1982, ASHRAE Standard 1982, Handbook of Applications). The percentage of outdoor air required to maintain a steady state indoor CO₂ concentration below a certain limit can be expressed as:

$$\% \text{Outdoor air} = \frac{(\text{No of people} * \text{Airflow rate per person} * 100)}{\text{Total flow of system}}$$

Equation 1

2.4 Health Effects and Standards

Staff and students are regularly exposed to low-level concentrations of inorganic gaseous pollutants with periodic exposure to higher concentrations (NAS 1991). Carbon monoxide poisoning is a well-established clinical fact. Acute illnesses and deaths have been reported as a result of CO poisoning while indoors. But young children and

persons with asthma, anemia, heart and hyper metabolic diseases are more susceptible (Hanson and Burroughs 1998).

Common health effects of CO exposure are dizziness, dull headache, nausea, ringing in the ears and pounding of the heart. Others are loss of alertness, impaired perception learning disorders, sleep deprivation, drowsiness, and confusion at higher levels, coma and eventual death. High exposure may induce unconsciousness resulting in damage to the central nervous system, the brain and the circulatory system (Health Canada 2000, Hutcheon and Handegord 1986).

Guidelines are in existence to ensure that indoor CO concentrations are maintained at acceptable levels. The United States National Primary Ambient Air Quality Standards (USNAAQS) (Table 1) specifies a short-term average concentration of CO in outdoor air. The short-term exposure guidelines (Table 2) for indoor CO concentrations have been specified by Health Canada.

Indoor carbon dioxide concentrations are usually higher than outdoor concentrations for more than 99% of schools (USEPA 1985); however CO₂ is not considered a contaminant by most researchers. Robertson et al. (1985) reported that serious health problems are observed from indoor concentrations above

Table 1 United States National Primary Ambient Air Quality Standards (Adapted from USEPA 1992).

Parameters	Average Concentrations
Carbon monoxide	10.4 mg/m ³ (9 ppm) (8 hours)
	40.3 mg/m ³ (35 ppm) (1 hour)
Carbon dioxide	540 to 810 mg/m ³ (300 to 450 ppm)

Table 2 Canadian Exposure Guidelines for Residential Indoor Air Quality (Adapted from ASHARE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality).

Parameters	Exposure Ranges
Carbon monoxide	$\leq 12.7 \text{ mg/m}^3$ (11 ppm) (8 hours) ¹ $\leq 28.8 \text{ mg/m}^3$ (25 ppm) (1 hour) ¹
Carbon dioxide	$\leq 6300 \text{ mg/m}^3$ (3500 ppm) ²

1 ASTER

Acceptable Short Term Exposure Range.

2 ALTER

Acceptable Long Term Exposure Range.

54,000 mg/m³ (30,000 ppm). Respiration is affected when the CO₂ concentration exceeds 27,000 mg/m³ (15,000 ppm), and exposure to concentrations above 54,000 mg/m³ (30,000 ppm) can cause headaches, dizziness, and nausea (Hines et al. 1993). This is not in agreement with Yocom et al. (1974) who reported that adverse health effects due to CO₂ exposure are observed above 9,000 mg/m³ (5,000 ppm). Health Canada (2000) guidelines for residential indoor air quality requires CO₂ limit for occupant health to be 6,300 mg/m³ (3,500 ppm). This limit was compared with baseline results obtained from this study.

Several standards have also been established for what is deemed an acceptable range for indoor carbon dioxide exposures. For information purposes, United States Occupational Health and Safety Standards (OSHA) specified time weighted average (TWA) of 0.5% by volume (OSHA 1982). ASHRAE 62-1981 Ventilation for Acceptable Indoor Air Quality standard recommended that continuous exposure should not exceed concentrations of 0.25% (Hanson and Burroughs 1993). The World Health Organization (WHO) recommended that concentrations of 0.1% should not be exceeded (Woods 1982). The Japanese indoor standard is set at 0.1% and Scandinavian countries have recommended a limit in the range of 0.07 to 0.08% (Croome and Sherratt 1977).

2.5 Exposure Assessment

Central to analysis of the baseline data in this study is the need to evaluate the impacts of exposure to low and high concentrations of CO and CO₂ in occupied spaces in schools. According to the American National Academy of Science, exposure assessment provides the fundamental basis for describing a population distribution (NAS 1991). Exposure assessment is therefore relevant because this study is aimed at describing the distribution of baseline data according to geographical regions or strata.

Exposure refers to the contact at a boundary between human and the environment at a specific concentration for a specific interval of time (NAS 1991).

Generally, exposure routes are through inhalation (lungs), ingestion (gastrointestinal tract) and dermal (topical) absorption. However, inhalation is the primary route of exposure for carbon monoxide and carbon dioxide (Ott 1990). Exposure limits derived for carbon monoxide and carbon dioxide were based exclusively on health considerations and the possibility of interactive effects, because both contaminants may likely be present in a classroom simultaneously (Honicky et al. 1985). Based on Health Canada (2000) and ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, two types of exposure limits are specified:

- Acceptable Long-Term Exposure Range (ALTER) is that concentration range which it is believed from existing information that a person may be exposed over a lifetime without undue risk to health.
- Acceptable Short-Term Exposure Range (ASTER) is that concentration range which it is believed from existing information that a person may be exposed over the specified time period without undue risk to health.

Exposure assessment of a particular space may either be carried out directly or indirectly (Ott 1985). The direct approach involves measuring the concentrations of the

pollutants inhaled, ingested or absorbed distally. This approach is best when data are limited and labour is intensive (Ryan and Lambert 1991).

The indirect approach involves the evaluation of an exposure profile obtained from human activity patterns (Rolloos 1977). This approach is more cost effective than the direct approach because unlike the direct approach, it eliminates the extra time necessary to obtain the prerequisite approval due to lack of human subject involved in the monitoring processes. This approach was adopted for this study; it involved the observation of the load profile of a space in each school included in the sample population. This was achieved through air monitoring of each randomly selected space in a school for six hours in order to observe the peak conditions of targeted IAQ parameters. Air quality instruments were also used to measure CO and CO₂ concentrations in occupied spaces. The results were analyzed based on ALTER and ASTER guidelines.

2.6 Comfort

Attitude of other people, organization of space, environmental and physiological factors combine to influence individual comfort, moods and learning abilities of students (Hines et al. 1993). Comfort zone refers to one in which there is freedom from annoyance and distraction (Croome and Roberts 1986). Croome et al. (1970) developed a comfort model, which relates comfort to work and activities carried out. Four cardinal dimensions, based on individual personality as defined by genetic endowment and environmental conditioning were reported to be responsible for individual comfort or discomfort experienced.

Physical and emotional sensation levels are two of the four cardinal dimensions. While the former define the personality of an individual, the latter refers to an

individual's reaction to changes in surrounding environmental conditions. Arousal level is the third dimension and is related to the attentiveness of a student while distraction as the fourth cardinal dimension level indicates the probability of concentration being high or low. Discomfort can be experienced if any of these levels falls outside the comfort zone but there are exceptions. For instance, it was established that at optimum arousal level the concentration of student may be so high that it is difficult to cause any distraction (Croome and Sherratt 1977).

2.7 Comfort Factors

In recent years there has been an influx of published information on the issues of comfort factors as it relates to the built environment (Awbi 1991). Comfort requirements and the quality of air necessary to achieve an acceptable indoor climate are essential in the design of ventilation systems. These depend on physiological and environmental considerations (Berglund and Cain 1989). A relevant physiological factor is the heat balance between the human body and the internal environment. Measurable environmental factors include temperature and localized thermal comfort, relative humidity and airflow or ventilation. Other factors are related to the user/occupier. These include the performed activity and the thermal resistance of clothes (Fanger 1988). This study is focused on the investigation of measurable environmental factors.

2.7.1 Temperature and Thermal Comfort

Temperature is defined as the state of either being hot or cold inside a building (Berglund and Cain 1989). Thermal comfort is achieved when the body temperature is in thermal equilibrium with the temperature of the environment in a space or inside the

building (Berglund and Cain 1989). As cited by ASHRAE Standard 55-1981, Thermal Environmental Conditions for Human Occupancy:

"Thermal comfort refers to that condition of mind, which expressed satisfaction with the thermal environment".

Fanger (1972) established three requirements for thermal comfort. First, the body must be in thermal equilibrium with the environment. This implies that a steady state condition is achieved when the rate of heat loss from the body to the environment balances the rate of heat production. Second, mean skin temperature must be at an acceptable level for the skin to feel comfortable. Third, there should be a preferred rate of sweating. For instance, at sedentary activity the individual prefers not to sweat. While the first requirement is essential for thermal comfort, collective studies have shown that physiological measures such as skin temperatures and sweat rate (second and third requirements) have little predictive values in assessing the response of an individual when concerning interaction between him and the environment within the comfort range (Bedford 1964, Wyon 1968, ASHRAE 1985, Handbook of Fundamentals).

Under normal conditions, the core body temperature of 37°C is maintained at a constant value over a wide range of ambient temperature. However, the skin temperature responds to changes in the environment usually different for different parts of the body. When the body is in a state of thermal equilibrium and is therefore comfortable, this variation in skin temperature is reduced (Awbi 1991).

Heat loss from the body to the environment is usually through conduction, convection and radiation. Conduction heat loss is usually through clothing. The heat transfer from between the body and the environment is primarily through convection, as a result of the movement between the body and air movement in a space. Heat loss by

radiation occurs between the surface of the body (clothing and skin) and the surrounding surfaces such as internal room surfaces and heat sources.

The most common gauge for thermal comfort is the ambient temperature (Hanson and Burroughs 1998). Typical temperatures are within the range of 20 to 23°C for winter and 23 to 26°C for summer seasons (Samet et al. 1987). The use of ambient temperatures in evaluating occupant comfort may depend on perception and often vary with age, physiology, activity, clothing, air movement, occupant preference and number of occupant in a space (Hanson and Burroughs 1998, Hines et al. 1993). Therefore ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy recommended the use of operative temperatures in evaluating indoor occupant comfort.

The indoor air analyzer (Q-track meter) used in this study is designed to measure operative temperatures (TSI 2002). Based on these operative temperatures, the ASHRAE comfort index specifies environmental conditions that are acceptable to 80% or more of occupants. It was initially developed for sedentary activity with normal winter or summer clothing ensemble but it can also be adapted for higher activity levels (Giovoni 1992). The comfort index for prolonged activities (Table 3) ranged from very cold and uncomfortable at 10°C to very hot and uncomfortable at 40°C. The neutral point of 25°C was deemed the most comfortable temperature (Croome and Sherratt 1977).

Table 3 **Comfort Index for Prolonged Responses (Adapted from ASHRAE Handbook of Fundamentals 1981).**

Temperature °C	Sensation	
	Temperature	Comfort
10	Very cold	Uncomfortable
10 – 15	Cold	
15 – 20	Cool	Slightly uncomfortable
20 – 25	Slightly cool	
25	Neutral	Comfortable
25 – 30	Slightly warm	
30-35	Warm	
35	Hot	
35 – 40	Very Hot	Very uncomfortable
Above 40	Limited tolerance	

2.7.2 *Relative Humidity*

Relative humidity (RH) is the amount of water vapour in the air compared to what it can hold at a given temperature (Hanson and Burroughs 1998). The relevance of relative humidity to indoor occupant comfort has been established by several studies (Hines et al. 1993, Croome and Roberts 1998, Robertson et al. 1985, Hanson and Burroughs 1998). The level of water vapour in air affects the body's response to temperature therefore the RH levels affects the range of temperature found to be comfortable to an individual (Hanson and Burroughs 1998).

The occupant comfort zone published by ASHARE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy employed both specific humidity and operative temperatures among other parameters (Figure 1). The dew point temperature is also used by ASHARE Standard 55-1992, Thermal Environmental Conditions for

Human Occupancy to explain the comfort zone of an occupant. The dew point is the temperature at which water vapour condenses on surfaces such as windows. This

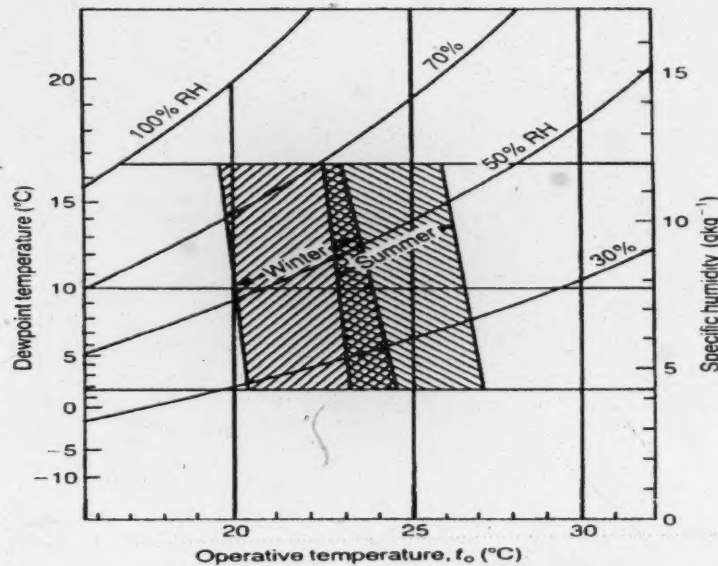


Figure 1 ASHRAE Standard 55-1992, Acceptable Ranges of Operative Temperatures (Adapted from Hanson and Burroughs 1998).

depends on the specific humidity of air and the higher the specific humidity, the higher the dew point (Awbi 1991). In this study, relative humidity levels in spaces are compared to ASHARE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy relative humidity standards.

A study by Bayer (2000) reported that spills on carpets and moisture from damp clothes and winter coats particularly in the winter are contributors to humidity levels in classrooms. Indoor humidity levels can also build up over winter periods due to reduced supply of outdoor air and increased recirculation of indoor air (Nevralla 1979). High humidity levels have been attributed as the one of the causes of stuffiness and musty smells causing occupant discomfort in classrooms. If prolonged, the musty smell translates to mould growth (Bayer 2000).

Discomfort as a result of high humidity also increases with increase in the thermal level of the environment and the level of sweating because at high humidity, evaporation from the skin is inhibited (Lind 1963). ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy regarding relative humidity is specified for summer and winter seasons. In the summer, 50% RH is specified for temperature range between 23°C to 26°C while in the winter, 30% RH is specified for temperatures ranging from 20°C to 24°C. Summer sampling was not represented in this study. As such, relative humidity data were analyzed based on winter comfort standards.

2.7.3 *Air Flow*

Air flows through the path of least resistance and moves naturally from a region of high pressure to a low-pressure region based on the principle of air distribution (Nancy et al. 1984). Since conditioned air from mechanical ventilation systems are supplied to air outlets located on ceilings at velocities much higher than the acceptable standard for an occupied zone, ventilation air moves into space where there is a lower pressure and replaces room or space air until ventilation air is in equilibrium with the room air. When there is a perfect piston flow (Figure 2a) perfect mixing (Figure 2b) is achieved at 0.5/hr air exchange rate (Hines et al. 1993).

Convective currents are one of the major influences on air motion in occupied spaces where air velocities are low (Croome and Roberts 1998). These are the result of both vertical and horizontal temperature gradients between the room air and air in contact with surfaces such as windows, external walls, furniture, equipment, etc. (Monschandrea and Relwani 1990).

Vertically, temperature gradients increase from room floor to ceiling and vary horizontally from wall to wall (Croome and Roberts 1998). Hamzawa et al. (1987) reported that at a sufficiently high vertical temperature gradient, there is a feeling of discomfort at the feet even though the body is thermally neutral.

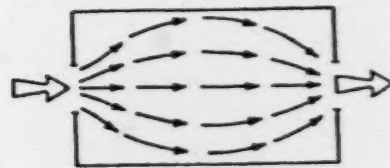


Figure 2a Piston Flow ($E_v > 1$)

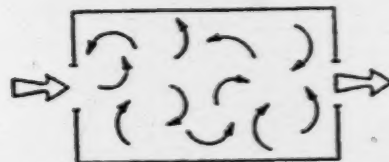


Figure 2b Perfect Mixing ($E_v = 1$)

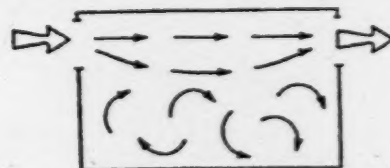


Figure 2c Short Circuiting ($E_v < 1$)

Ev: Ventilation effectiveness

Figure 2 Ventilation Air Movements (Adapted from Hanson and Burroughs 1998).

Convective currents also reduce the circulation of airflow resulting in stagnant zones or "air short circuiting" (Figure 2c) where there is poor mixing of ventilation air with room air (Hanson and Burroughs 1998). Drafty conditions are caused when air

motion is higher than specified by the design conditions of the ventilation system. When air motion is below the design value, stuffy conditions occur (Knight 1986).

In order to ensure a comfortable environment, ASHRAE Standard 55 - 1981, Thermal Environmental Conditions for Human Occupancy recommended air velocities of 0.25 m/s for summer and 0.15 m/s for winter seasons. Rather than using an air velocity standard, this study is focused on investigating the airflow rate entering a classroom as a means of evaluating occupant comfort. Therefore ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality specified airflow rate per person was used as a reference.

The location of terminal air devices such as supply diffusers and air vents are important to achieve high ventilation efficiencies. Most empirical models used to achieve thermal control for a comfortable indoor environment are based on the assumption that the location of air supply and return diffusers are not important if the supply diffusers are properly located to provide optimum thermal conditions. As a result there may be thermal uniformity in an occupied space but also contaminant stratification thus allowing contaminants to be undetected when they are at thermal equilibrium with the indoor environment (Woods 1986).

2.7.3.1 Ventilation Effectiveness (E_v)

The fraction of outdoor air delivered to a space that actually reaches the occupied zone has made the study of ventilation effectiveness relevant in reference to indoor occupant comfort (Woods 1986). As mentioned previously, temperature gradient and "air short circuiting" may reduce ventilation effectiveness in occupied spaces. Published data suggests that ventilation effectiveness may be as low as 0.5 and 1.0 for a non-uniformly mixed space and perfectly mixed spaces, respectively. When piston flow

occurs, ventilation effectiveness is greater than 1 (Figure 2) (Hanson and Burroughs 1998).

The ventilation effectiveness of outdoor air delivered to an occupied space is expressed in terms a mixing factor S and a recirculation factor R (ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality):

$$Ev = \frac{[1 - S]}{[1 - RS]} \quad \text{Equation 2}$$

Ev = ventilation effectiveness

S = fraction of bypass supply air that goes to the return inlet without mixing at the occupied level.

R = recirculation factor.

This equation was not applied in this study. Rather ventilation effectiveness was evaluated based on indoor levels reported.

Only classrooms were targeted by this study. Spaces such as gymnasium, libraries, locker room, utility rooms, etc were excluded. This was, in part, to meet the project scope and because the ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality used to compare baseline levels vary from space to space. Some occupancy was mandatory during sampling. This is because when spaces are unoccupied, ventilation is not generally necessary unless it is needed to prevent accumulation of contaminants that constitutes a danger to occupant, contents, or structure (Croome and Sherratt 1977, Woods 1986, Relwani et al. 1987).

Where more than one space was served by a common supply system, the ratio of outdoor to supply air required to satisfy the ventilation and thermal control requirements

may differ from space to space. In such cases, ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality recommended Equation 3 to determine the quantity of outdoor air delivered to a particular space. This equation was not employed during data analyses because there were insufficient details in available school blueprints to identify duct lines leading to particular spaces. It was expected that ventilation data concerning central ventilation systems may indicate some discrepancies.

$$4Y = \frac{X}{1 + X - Z}$$

Equation 3

$$Y = \frac{V_{ot}}{V_{st}} \quad X = \frac{V_{on}}{V_{st}} \quad \text{and} \quad Z = \frac{V_{oc}}{V_{sc}}$$

Where

Y = corrected fraction of outdoor air in system supply

X = uncorrected fraction of outdoor air in system supply

Z = fraction of outdoor air in critical space (the critical space is that space with the greatest fraction of outdoor air in the supply to the space).

V_{ot} = corrected total outdoor air flow rate

V_{st} = total supply flow rate, i.e. the sum of all supply for all branches of the system

V_{on} = sum of outdoor air flow rates for all branches on system

V_{oc} = outdoor air flow rate required in critical spaces

V_{sc} = supply flow rate in critical space

2.8 Comfort Standards

The comfort standards used in this study were after ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy (Table 4). Standards from Table 4 compare baseline levels of relative humidity and temperatures reported from individual stratum as defined by the experimental design. In addition, ASHRAE Standard 62-1989 and ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality (Table 4) were used as a comparison for baseline ventilation rates of individual strata.

Table 4 Criteria for Maintaining Indoor Comfort (Adapted from Hanson and Burroughs 1998).

Parameter	Comfort Standard
Temperature	20°C to 24°C ¹
Relative humidity	30% RH ¹
Airflow rate per person	25.5 to 34 m ³ /hr (15 cfm to 20 cfm) ²

1 ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy

2 ASHRAE Standard 62-1989 and ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality

2.9 Heating Ventilation and Air Conditioning (HVAC) Systems

2.9.1 Basic Processes of HVAC Systems

HVAC systems are widely adopted in ensuring residential indoor air quality in schools (Giovoni 1991, Bedford 1964). Heating and dilution ventilation have been identified as two main processes carried out by HVAC systems. A mixture of outdoor air and a portion of indoor air are filtered, and heated to an appropriate indoor air temperature with the aid of heating coils present in the HVAC systems. Conditioned air with an optimum purity and temperature is then supplied into occupied spaces. Through ventilation processes, air supplied dilutes indoor air to acceptable standards and returns a portion of indoor contaminated air, which mixes with outdoor air to continue the cycle.

Either humidification or dehumidification processes are employed so that air supplied indoors is acceptable in terms of indoor relative humidity conditions (Hanson and Burroughs 1998). Humidification occurs when water is introduced into air streams at a temperature above the dew point with the purpose of adding moisture to air while dehumidification occurs when water is extracted from air (Croome and Roberts 1998). The relevance of these processes to this study is limited because of the climatic conditions in Alberta.

Air conditioning is another feature of HVAC systems commonly employed in hot climates. During field investigation, it was observed that air conditioning systems were absent and dehumidifiers were decommissioned. Air-conditioning processes are ignored in this study.

2.9.2 Components of HVAC System

The components of a typical HVAC system are depicted in Figure 3. Their basic functions serve to describe heating and ventilation processes before variations of HVAC systems are considered.

Outdoor Air Intake (OAI)

This provides an opening for the passage of air into the filters. It consist of louvers, which control the amount of air entering into the system and the presence of a bird screen just inside the OAI serves as a protection against bird droppings and large objects. The OAI is usually located away from dense traffic, chemical factory or landfill sites.

Dampers

These consist of exhaust, mixing and outside dampers designed to control the amount of air exhausted, admitted, recirculated and mixed respectively.

Mixing Plenum

This compartment facilitates the mixing of outdoor air with indoor recirculated air. Any dirt in this area could be transmitted into the ventilation system if it is small enough to go through the filters (Hanson and Burroughs 1998).

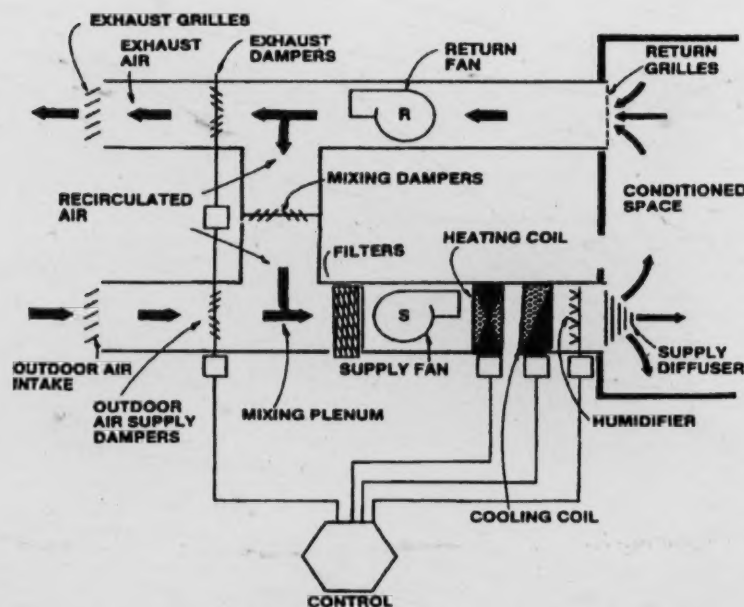


Figure 3 Typical Mechanical Ventilation System (Adapted from Hanson and Burroughs 1998).

Filters

The primary role of filters is to screen particles, pollen dust, fibers, etc. from air in order to protect the downstream components. Studies have indicated that air is a

natural reservoir for fungi therefore outdoor air as well as recirculated air is filtered (Hanson and Burroughs 1998). Observations made from school investigations indicated that most commonly used filters are box or throwaway and dual filters.

Regular maintenance is necessary to achieve high filter efficiencies. Evidence has shown that media filter buildup increases collection efficiency up till when a filter becomes clogged and the critical airflow rate is decreased (Croome and Roberts 1998). One way to ascertain the condition of filters is to check if the filter mediums are transparent to light (Beaupre 2001, 2002).

Design considerations that affect filter maintenance include accessibility and fitting. Loosely fitted filters may result in increased air velocities such that some portion of air bypasses the filter (Hanson and Burroughs 1998).

Supply fan

This enables air to be blown through filters, across heating / cooling coils into the humidifier and then through supply diffusers to occupied spaces.

Coils

These consist of heating and cooling coils. The heating coils are used in heating outdoor air to an adequate temperature before entering into the space. Coiling coils are mostly employed in air conditioning systems (Croome and Roberts 1998).

Humidifier

This component injects water vapour or steam into air to increase the relative humidity. It is mostly employed in the winter to increase the moisture content of outdoor

air (Hanson and Burroughs 1998). None of the schools investigated in this study had this facility in operation.

Control

This controls the operation of HVAC components (outdoor air intake, heating and cooling coils and the humidifier) so that the desired comfort and air quality is achieved. Energy efficiency is a major consideration.

Supply diffuser

This is placed strategically on the ceiling for effective flow and mixing of air currents within a space. There are mostly square and circular diffusers. The square diffusers were predominant in schools investigated and have varying sizes, with the most common being 0.608 m by 0.608 m (2 ft by 2 ft) diffuser.

Return Air Grilles and Return Fan

Return air grilles ensure that air is removed from a designated area through the return grille to ensure circulation. Return fan facilitates the return air to be drawn from a classroom and delivered into the mixing duct.

Exhaust and Intake Grilles

Mounted on external walls, grilles and louvers allow for the discharge of return air and intake of outdoor air. Intakes and exhaust grilles have bird screens to keep birds, rodents, and snakes out of the screen.

2.10 Variations in HVAC Systems

Variations of HVAC systems commonly employed in schools are classed as either Terminal Unit Ventilation System or Central Ventilation System. Both classes operate under any of three ASHRAE's recommended operational sequences (ASHRAE 1982, Handbook of Applications, Weston 1985). Cycle I operational sequence supplies 100% outdoor air at all times except during the warm up stage. This applies mostly to unit ventilators and is applicable in very warm climates. Cycle II supplies a set minimum quantity of outdoor air during the heating stage, which is gradually increased when cooling is required. This sequence is also applicable to unit ventilators and is most commonly used in temperate climates such as Alberta. Cycle III supplies a variable amount of air as required for maintaining a fixed temperature (typically 12.8°C). This is the typical sequence used for southern climates but is also adapted for mechanical cooling used in variable air volume systems (Hanson and Burroughs 1998).

2.10.1 Terminal Unit Ventilators

For more than 60 years, the unit ventilator has been the traditional method of heating and ventilating single spaces in schools (Croome and Roberts 1998, Weber 1984). Typically, a unit ventilator circulates a total of 1699 m³/hr air, consisting of 679 m³/hr as minimum outdoor air (Kohler 1981). Most unit ventilators are designed for 100% outdoor air intake, however less than design value is operational in most systems due to energy conservation (Fanger 1988). During field investigations of schools that participated in this study indications were that the outdoor to indoor ratio was approximately between 30% : 70% and 20% : 80%.

Cycle II of ASHRAE's recommended operational sequence is more commonly adopted because it enables a variable supply of outdoor air. Reports have indicated that the efficiency of a ventilation system depends on the heating and cooling load of a classroom when cycle II is adopted (Croome and Roberts, 1981, Croome and Sherrate 1977). Heating of outdoor air is usually required at the beginning of a school day due to lack of heat gains through the night from the ventilation system being turned off. However, due to the combination of internal heat gains from students, lights and solar gain in an occupied classroom, cooling may also be required. Thus even on a cold winter day, increasing the mount of outdoor air supplied indoor may be necessary to cool the indoor environment (Goodfellow 1988).

The heat source for the outdoor air is generated from hot water boilers and steam boilers. Hot water is supplied to heating coils (Figure 4) through a series of ducts (Woods 1986). When the air mixture comes in contact with the coil, the air mixture is heated up to approximately 18°C, slightly cooler than room temperature (Weber 1984). The most common unit ventilator has no control over water moving through the water coil. Instead, a thermostat and temperature controller regulates the temperature of the face and bypass damper, which in turn controls the quantity of ventilation air introduced to the coils. This ensures that air is either cooled or heated as specified by the thermostat. On a very cold day, the indoor air will be recirculated continually and ventilation is controlled solely by the thermostat (Hanson and Burroughs 1998, ASHRAE 1985, Handbook of Fundamentals).

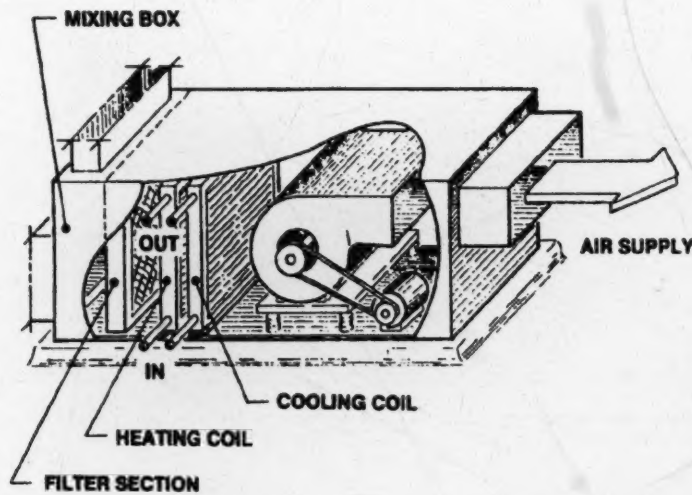


Figure 4 Typical Unit Ventilator (Adapted from Hanson and Burroughs 1998).

2.10.2 Central HVAC System

A central HVAC system refers to a central air-handling unit that distributes a mixture of outdoor air and recirculated air through ducts to control terminals located in individual zones (Meyer 1983). Central HVAC system can be classified as Constant Volume or Variable Volume Central Ventilation Systems (Meyer 1983, Hanson and Burroughs 1998, ASHRAE 1985, Handbook of Fundamentals).

2.10.2.1 Constant Volume Central Ventilation System

A constant volume system is a type of central ventilation system which supplies a fixed amount of air distribution at all times and is predominately employed in large open spaces such as auditoriums, dining halls, gymnasiums etc (Weber 1984). The constant volume system could be used to supply a fixed volume of air to either a single zone or multiple zones. When employed as a single zone system, a thermostat usually controls

the temperature of hot water to the coil and the fan always operates on the same flow rate (Meyer 1983).

The multizone air handler (Figure 5) has one constant volume fan which supplies heated and cooled air to several individually controlled zones by varying the amount of hot and cold air to the zone. The heat requirement of each room is controlled by individual room thermostats. The unique advantage of the multizone system is that it provides temperature control and an excellent comfortable indoor environment (Hanson and Burroughs 1998). But one of its limitations is the amount of expense required in terms of utility. The duplication of ductwork is also expensive, takes more space and consumes more time during maintenance (Croome and Roberts 1998).

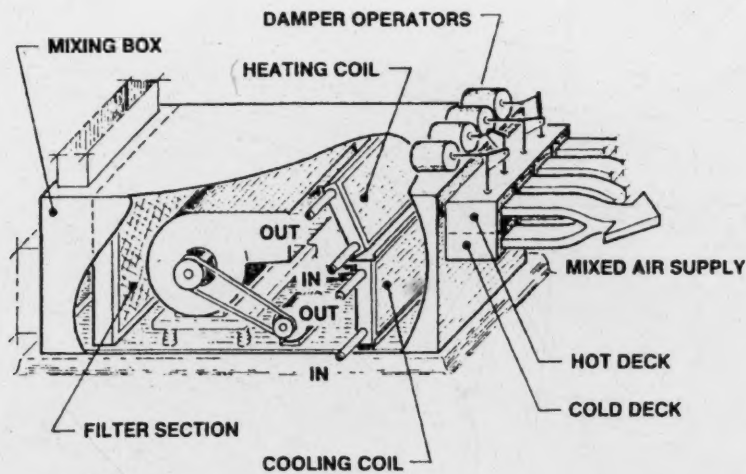


Figure 5 A Multi Zone HVAC System (Adapted from Hanson and Burroughs 1998).

2.10.2.2 *Variable Air Volume (VAV) Central Ventilation Systems*

The development of the "variable air volume" air distribution systems (Figure 6) has provided designers a more efficient means of distributing comfort heating and cooling to building zones. As reported by Hanson and Burroughs (1998), VAV systems are designed to meet all building load requirements while, at the same time, allowing energy savings at the fan and the heating/cooling plant.

This is achieved by controlling the amount of heated or cooled air flowing through the VAV system. Conditioned air is supplied to spaces through "VAV boxes" containing dampers, which restrict the flow as dictated by the room thermostat.

In a VAV system, the amount of outdoor air admitted at any one time depends upon the total amount of air circulated and the percentage of outdoor air brought in by the economizer cycle control. As the VAV system modulates from its cooling design level (maximum) to its heating design level (minimum), the total air circulation rate reduces. Since outdoor air is admitted as a constant percentage of the total air circulated, the outdoor air intake is reduced proportionately. If room temperature conditions are satisfied, the VAV could theoretically shut off the flow of air. However, health and safety reasons dictate that a minimum flow of air be maintained (Hanson and Burroughs 1998).

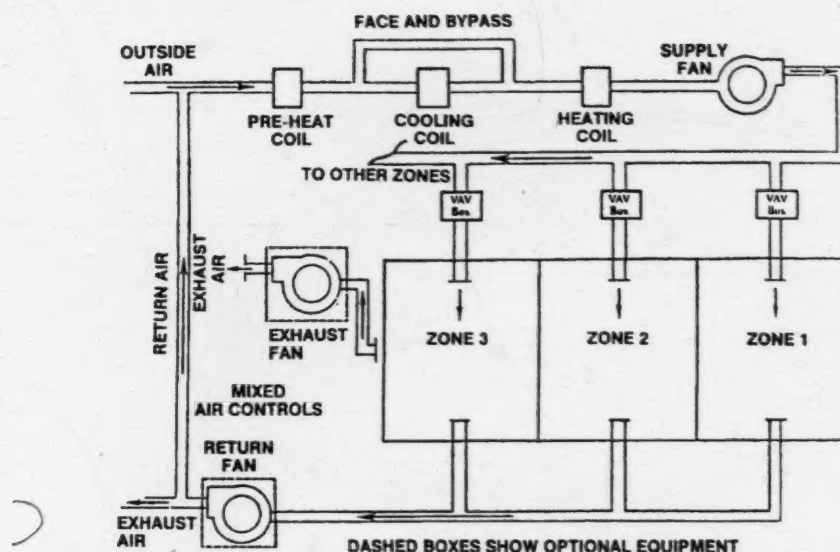


Figure 6 Duct Line Showing Variable Air Volume (VAV) System (Adapted from Hanson and Burroughs 1998).

2.11 Design Considerations for ensuring Comfort in Classrooms.

Energy use has become an increasingly important consideration in educational facilities and specifically in HVAC design. The design for an optimum indoor environment for learning must consider heat loss, heat gain and air movement (Gagge et al. 1977, ASHRAE 1982, Handbook of Applications). It has become increasing evident that optimum temperature indoors is the basis for achieving occupant comfort.

2.11.1 Heat Load Considerations

Thermal control is significant in maintaining occupant comfort and high ventilation efficiencies (Gagge 1971). Excessive variations in temperature may cause discomfort thus the relevance of heat load estimates of probable heat losses of each space to be

heated. In order to estimate the heat load of spaces, outdoor climatic conditions, transmission losses through confining walls, floors, ceilings and infiltration heat losses were considered (Goodfellow 1988). Infiltration heat loss was ignored in this study.

2.11.1.1 Outdoor Climatic Design Conditions

There are several climatic zones and a system optimal for one may not be the best choice for another. Several studies have established that seasonal changes have tremendous effects on indoor heat load (Hanzawa et al. 1987, Croome and Sherrate 1977, ASHRAE 1982, Handbook of Applications). Climatic changes affect energy consumption so much so that more outdoor air is supplied in the summer and very little in the winter due to the amount of energy required to heat outdoor air to the required indoor temperature. Accounting for such variations in HVAC design present some challenges. As cited by Hines et al. (1993), the ideal solution would be to design a system with the maximum capacity equal to the heating load developed during the most severe weather conditions but cost is a limiting factor. Studies of weather records have also shown that the most severe weather conditions are not repetitive every year (Knight et al. 1986, Koestel and Tuve 1965, Janssen et al. 1982). As such, if maximum design conditions for heating systems correspond to the most severe conditions, there would be considerable excess capacity during most of the operating life of the systems. Such systems obviously would not be cost effective in view of energy conservation (Hines et al. 1993). In many cases, occasional failure of a heating plant to maintain a preselected indoor design temperature during brief severe weather is not critical (Goodfellow, 1988)

2.11.1.2 Indoor Design Conditions

The most relevant indoor conditions to be maintained are temperature and relative humidity of the air at the breathing zone, 0.9 to 1.26 m above the floor. This indicates the average conditions that are not affected by abnormal or unusual heat gains or losses from the interior or exterior (Dols and Persily 1993, ASHRAE 1982, Handbook of Applications).

The design indoor air temperature may depend on seasonal changes. Warmer walls are usually encountered during the cooling seasons. As a result, design conditions are usually lower than stated for optimum comfort. ASHRAE Standard 55-1992, Thermal Environmental Conditions for Indoor Occupant Comfort recommends 23.8°C as a design temperature, which is slightly lower than the optimum range of 24.7 to 25.3°C when walls are at room temperature.

During the heating season, the mean radiant temperature is normally lower than air temperature. Thus ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy suggested a higher temperature than 23.8°C for comfort conditions. In unusual conditions such as inside partitions and exposed adjacent rooms of widely different temperatures, the design could be adjusted to maintain comfort conditions. Modera and Persily (1995) emphasized that mean radiant temperatures should not be corrected outside the range of 21 to 26.7°C.

Ceiling temperatures may vary beyond the comfort range and should be considered in the overall heat transmission to the outdoors. A 23.8°C difference between indoor and outdoor ceiling conditions would be expected for normal applications (ASHRAE 1982, Handbook of Applications).

The effects of clothing on optimum indoor design temperature are important because ASHRAE comfort criteria were based on tests performed with lightly clothed subjects. The overall effect is accounted for by 23.8°C design temperature for both winter and summer seasons. Normal conditions may vary between 23 to 25°C (Dols and Persily 1993).

2.11.1.3 Temperature in Unheated Spaces

The heat losses from heated to unheated room are based on the estimated or an assumed temperature. This lies in the range between the indoor and outdoor temperatures, depending on the relative areas of the surfaces adjacent to the room and those exposed to the outside. If both surfaces are approximately the same and if coefficients of transmission are approximately equal, then the temperature in the unheated space may be assumed to be the mean of the indoor and outdoor design temperatures. If however some differences occur, the temperature in the unheated space is estimated by (ASHRAE 1982, Handbook of Applications):

$$t_u = \frac{t_i(A_1U_1 + A_2U_2 + \text{etc}) + t_o(A_aU_a + A_bU_b + \text{etc})}{A_1U_a + A_2U_2 + \text{etc} + A_aU_a + A_bU_b}$$

Equation 4

Where

- t_u = temperature in unheated space, °C
- t_i = indoor design temperature of heated room, °C
- t_o = outdoor design temperature, °C
- $A_1, A_2, \text{etc.}$ = areas of surface of unheated space adjacent to heated space, m²
- $A_a, A_b, \text{etc.}$ = areas of surface of unheated space exposed to outdoors, m²

U_1, U_2 , etc. = coefficients of transmission of surfaces of A_1, A_2 etc.

U_a, U_b , etc. = coefficients of transmission of surfaces A_a, A_b , etc.

2.11.2 Controls

The automatic control of the operations of ventilation systems and temperatures are a necessity if comfortable conditions and efficient operation are to be obtained. Proper application of controls may return the investment within a year or two through savings in labor and fuel. Such controls must consider rapid changes from heating to cooling in a few minutes when a class is occupied after morning warm-up because of the heat suddenly supplied by lights and students (Modera and Persily 1995).

The ideal climate control system for educational facilities should be able to serve diverse areas regardless of the use of the various spaces involved. For example, when showing movies or videotapes with the lights turned off, heating may be required, while a nearby area may require cooling. During evenings and weekends, some areas may be used for special events or instructions while other rooms are unoccupied. These varying and often unpredictable conditions are best met by separate control of each space (Wang 1975).

Janssen et al. (1982) reported that ventilation equipment should be capable of efficient operations at extremely low and variable loads, as this would ensure future expansion with minimal investments. Due to a large heating and cooling load associated with ventilation when spaces are not in use, Love (1985) recommended that provisions should be made in control systems to close the outside air dampers when spaces are not occupied.

2.11.3 Classroom Load Profile

The classroom load profile is significant in estimating the heat load on a heating system. Variations and times of occupancy require a flexible means of heating, cooling and automatic control to conserve energy and reduce operating costs. Some cooling may be required all year when an interior room is occupied and the lights are on (Gagge 1971, ASHRAE 1982, Handbook of Applications). Irregular occupancy of educational facilities may occur. It is an inaccurate assumption that schools are fully occupied from 8:00 am to 3:30 pm before being vacant (Croome and Sherrate 1977). School custodians, adult education and civic affairs such as band practice and Boy Scouts meetings make the total occupancy time far longer than the normal school year of 1,400 to 1,500 hours (Chang and Lee 1988).

2.11.4 Financial Considerations

Financial consideration is a significant factor in any design. Indoor air quality and occupant comfort must be correlated to the available funds. This is particularly true with educational facilities because most educational constructions are financed using public tax funds and by selling tax-free bonds with payback periods ranging from 20 to 40 years (Weber 1984, Gao 1996). All costs including initial, operating and maintenance costs are simultaneously paid by taxpayers over an extended period of time. Therefore, the present consensus among educational facility planners and owners is that the highest quality construction, which can be afforded, should be built; since these facilities must normally serve over such a long period (ASHRAE 1982, Handbook of Applications, Croome and Sheratt 1977, Gao 1995)

2.11.5 Environmental and Regulatory Considerations

Many states have special regulations for school buildings such as building ventilation, and noise control codes which may impact on the design considerations (Sundell 1982). Ventilation requirements vary in different states and different localities (Leaderer et al 1985). If the regulations are poor or nonexistent, good design practice generally dictates minimum air change required and the outdoor air quantities. In more severe climates, considerations may be given to the treatment of return air to reduce odours and fumes. However, since schools need cooling much of the time even in cold climates, reduction in ventilating air may not save substantial amounts of energy and should be carefully analyzed (Love 1985).

CHAPTER THREE

3.0 DEVELOPMENT OF STUDY OBJECTIVES

Obtaining relevant information from field studies is necessary to achieve the overall objective of this study, which is to obtain baseline data for IAQ parameters (carbon dioxide and carbon monoxide), and comfort factors (temperature, relative humidity and ventilation rates). Achieving this overall objective was based on obtaining an experimental design developed to ensure the precision of the aforementioned parameters. Several factors were examined in the development of the experimental design.

3.1 Justification for Study

The Board of trustees for Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools consult with parents to ensure that the school system in each region (Edmonton and Elk Island district) meet the requirements of parents. They also oversee the efficient running of schools and execute strategic decisions including those concerning IAQ issues. In 1998, a Common School Health Agenda was established between Capital Health Authority and Edmonton Public Schools with a goal to *"Improve health and education potential of all children by building the capacity of the children and their families to make healthy choices within supportive work environments"*. In accordance with this agreement, the study of IAQ in Edmonton Public Schools, ELK Island Public Schools and ELK Island Catholic Schools received full support from Capital Health and Edmonton Public School Board.

There were no records of previous indoor air quality crises in the schools from the aforementioned school boards. Rather, this study was a proactive action aimed at obtaining relevant information about indoor environmental conditions of Edmonton Public Schools, ELK Island Public Schools and ELK Island Catholic Schools. Findings would serve as a reference tool for schools boards to base strategic decisions regarding work and learning conditions for staff and students. It would also serve as a reference for addressing ventilation system related issues.

The steering committee for the project consisted of a representative from Capital Health Authority as the project manager and principal investigator. The project coordinators were representatives of Edmonton Public School Board, Elk Island Public School Board, Elk Island Catholic School Board and Alberta Infrastructure. Alberta Infrastructure was included to provide details of school buildings such as blueprints. Representatives from the University of Alberta under the supervision of Dr. Warren Kindzierski acted as project consultants and field investigators thus providing the expertise required for a comprehensive investigation.

3.2 Description of Study Area

This study was conducted in schools situated in Edmonton and surrounding areas (Capital Health Region). The City of Edmonton is bordered by Sherwood Park on the east and the City of St. Albert on northwest. The entire study area consisted of schools located in the City of Edmonton, Sherwood Park and Strathcona County.

School districts are categorized according to regional divisions. Edmonton School district is registered as region 7 while Elk Island Public and Elk Island Catholic Schools are registered under regional division 14 and 41 respectively (Figure 7). Edmonton school district consists of both Edmonton Public and Edmonton Catholic Schools

divided into 9 wards from A to I. Elk Island school district consists of schools located in Sherwood Park, the City of Fort Saskatchewan, the Town of Vegreville, Strathcona County, the County of Lamont and the western portion of the County of Minburn (Kuo et al. 1985).

There are three existing school categories with an average class size of 30 students. School categories are Elementary (grades 1 to 6), Junior High (grades 7 to 9) and Senior High (grades 10 to 12). Schools are usually located far from dense traffic and are commonly found in living communities.

3.3 Approval of Study

The approval for this study was sought and obtained from the Health Research Ethics Board (HREB). The Health Research Ethics Board is a joint committee of the Faculty of Health Sciences in the University of Alberta, Capital Health Authority and Caritas Health Group in Edmonton, Alberta (HREB 2001). The purpose of the review board was to ensure that the rights of study participants were not violated.

HREB review panels are of two types: HREB-A focuses on biomedical (invasive) research and HREB-B focuses on health (noninvasive) research. This study falls under HREB-B because field sampling conducted was noninvasive.

Panel B is further divided into several levels consisting of Full HREB Review, Expedited Review and Provisional Ethics Review. Full HREB Review targets studies where contacting human subjects are involved while Expedited Review are for those studies involving no contact with human subjects or are deemed to be of minimal risk. Provisional Ethics Review deals with provisional research approval before funding is finalized.

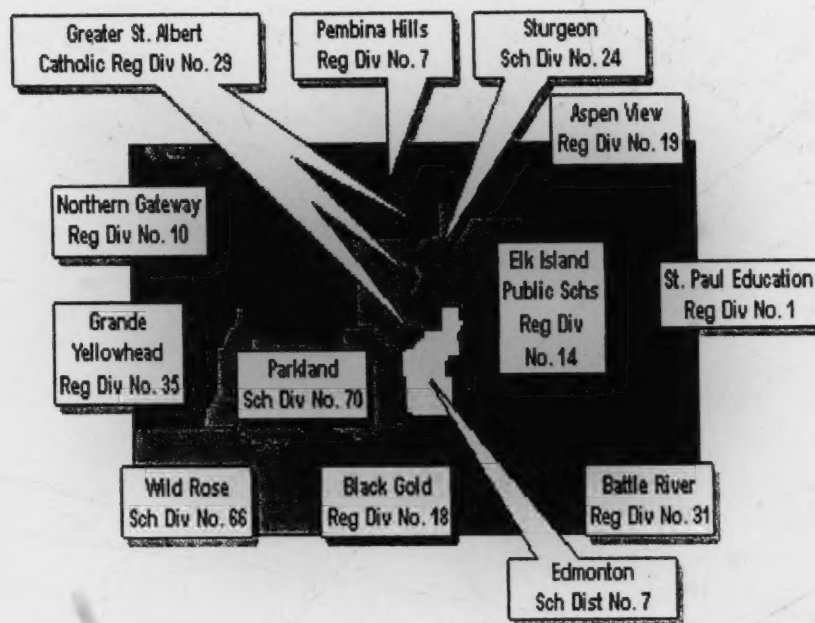


Figure 7 Regional Division of Schools in Central Alberta (Adapted from Lugg and Batty 1998).

Expedited review was adopted for this study. Obtaining study approval through expedited review involved the following: First, a completed questionnaire (Appendix 1) requesting an HREB review was forwarded to the administrative assistant of the HREB expedited review panel. Approximately one week later, the presence of field investigators was requested before the HREB expedited review panel (June 6, 2001). This involved a brief review of research objectives and clarifications on the involvement of study participants as well as the use of sampling instruments. Approximately one week later, the HREB review committee forwarded a few revisions regarding the proposed research. The revisions were incorporated into the study, after which an approval (Appendix 2) was given for the study. It is worth noting that the approval process did not constitute any delay in the study and was carried out simultaneously with literature review and the development of questionnaires.

3.4 Experimental Design

The efficiency of any investigation is considerably enhanced by a right choice of the sampling design (Cochran 1963). A faulty design would contribute to erroneous inferences about the sample population (Grant and Leavenworth 1980). The experimental design for this study was primarily aimed at obtaining a sample population, which would provide relevant and reliable information to meet the overall objective of establishing baseline data of targeted parameters.

A stratification with random sampling design was deemed the most appropriate in obtaining precise estimate of IAQ parameters and comfort factors relevant to the overall study objective. In a stratified random sampling design, the population is first divided into subpopulations called strata such that the addition of each stratum makes up the total population. A random sample is then drawn from each stratum independent of other

strata (Cochran 1963). The stratified random sampling design was employed for the following reasons: First, there was some prior knowledge about the total population obtained from administered questionnaires. Second, Prasad (2000) reported that the stratified sampling design results in a considerable increase in precision of the parameter estimates. Furthermore, a stratum containing a sample in proportion to the total population has a smaller variance than a random sample of the same size (Prasad and Rao 1967).

To ensure the precision of the sample population obtained for each stratum, deep stratification was avoided to prevent sample sizes that were insignificant in yielding reliable estimates of IAQ parameters and comfort factors (Cochran 1963). Deep stratification refers to the sub division or stratification of a stratified sample into several levels such that the latter level is obtained as a result of the stratification of the former level. A characteristic of deep stratification is that the size of each stratified sample decreases with increasing level of stratification and yielding small area domain that are likely to yield unacceptable standard errors (Prasad and Rao 1967). Based on findings reported by Prasad (1969), a two - level estimator leads to considerable gain in efficiency of approximately 123 to 184%. However, increasing the numbers of estimators above two levels also results in decreasing efficiency. A third estimator was therefore discarded in favour of two, and two-level stratification with random sampling design was developed.

3.4.1 First Level Stratification

A total of 217 schools participated in this study. This comprised of 189 schools from Edmonton Public Schools (EPS), 20 schools from Elk Island Public Schools (EIPS) and 8 schools from Elk Island Catholic Schools (EICS).

The schools that participated in this study were originally located in different geographical regions based on Alberta Infrastructure guidelines. Since geographical location was a common characteristic to all the schools, it was chosen as the first parameter used to obtain the first level stratified samples (Appendix 3). Using Alberta Infrastructure guidelines, six geographical zones were identified as North West (NW) with 39 schools, East (NE) with 39 schools, Central (C) with 33 schools, South West (SW) with 35 schools, South East (SE) with 43 schools and Elk Island District (Elk) with 28 schools. The first 5 strata consisted of Edmonton Public Schools while the sixth stratum was made up of a combination of Elk Island Public and Elk Island Catholic Schools. Geographical stratification ensured that all the schools were proportionally distributed within the Capital Health Region. It also ensured representation of funding provided by the school boards. Furthermore, since the sample population in individual stratum was randomly generated, the conditions of schools and where they were located (i.e. the geographical zones or strata) had little or no impact on the accuracy, reliability and inferences made from the stratified sample (Prasad 2001).

3.4.2 *Second Level Stratification*

Based on prior knowledge regarding the conditions of schools investigated, several characteristics were considered however, evidence of water damage was chosen as the second stratification level because it provided relevant information to meet the study objectives. Evidence of water damage could be related to either past or future presence of mould (Hanson and Burroughs 1998). It could also increase indoor moisture content and consequently indoor relative humidity levels (Croome and Roberts 1991). Two-level stratification of the school population is depicted in Figure 8. The number of schools in each stratum based on the two-level stratification is provided in Appendix 4.

Before arriving at evidence of water damage as the second estimator, other criteria were considered and rejected (Appendix 5). The rejected criteria were school grade, utilization rate, foundation types and building structural differences. The influences of these rejected criteria on the sample population were minimized by random sampling techniques used to obtain the sample population.

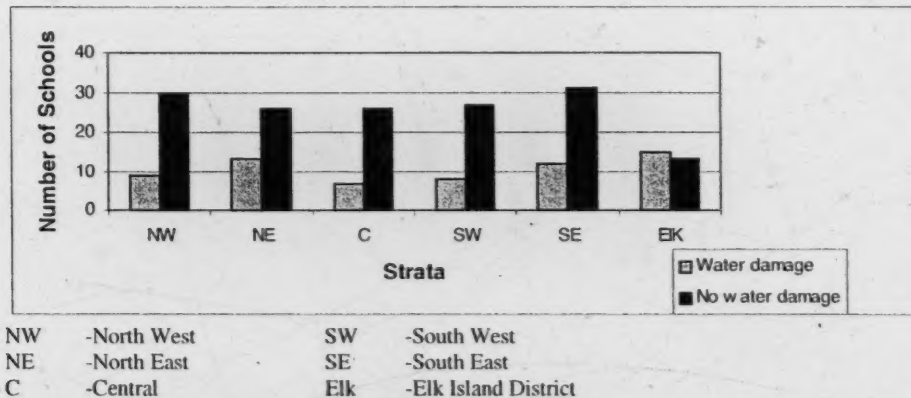


Figure 8 Two-Level Stratification of Total Population.

School grade was considered as a second stratification level. Two grade levels were identified as kindergarten (K-9) and grades 9 to 12. However, it was discovered that there were significant variations in this dichotomy; only grades 9 to 12 were represented in EPS, EIPS and EICS.

Utilization rate was originally considered as a stratification level in order to show a possible correlation between schools' full time enrollment and IAQ concerns. The utilization rate data indicated a continuous dataset, which could be a source of variance in the final results (Appendix 5).

Foundation types identified as slab on grade, crawl space and basement were considered as a second stratification level because studies indicated that the temperatures of different types of foundation could affect floor temperatures, which would

consequently impact on the thermal control of spaces (Hines et al 1993, Croome and Roberts 1991). This criterion was rejected to avoid sampling errors.

Building structural differences identified as either portables or pods were also considered because Bayer et al. (2001) reported that portable structures have indicated a significant presence of mould. However, the blueprints of some schools were not specific as to which structures were considered portables or pods. This was because some structures were initially regarded as portables but considered otherwise when other school structures were built around them. This criterion (portable or pod) was therefore rejected. Never the less, some pods and portables structures were included in the baseline sample due to random sampling techniques employed in the sample selection process.

3.5 Determination of Sample Population

Sample size determinations have been well documented in various studies (Cochran 1963, Grant and Leayenworth 1980, Prasad and Rao 1969). However, in order to achieve the overall objective defined by this study (baseline data of IAQ parameters and comfort factors), Jhandri (2001) and Prasad (2001) recommended two methods: The first method involved sampling the total population of 217 schools. The second method was to obtain a sample population possessing characteristics that represent the total population. The former is cumbersome, more costly and subject to sampling errors while the later is more efficient and more cost effective (Cochran 1963). The second method was therefore adopted and a two level study called baseline and subset studies were designed.

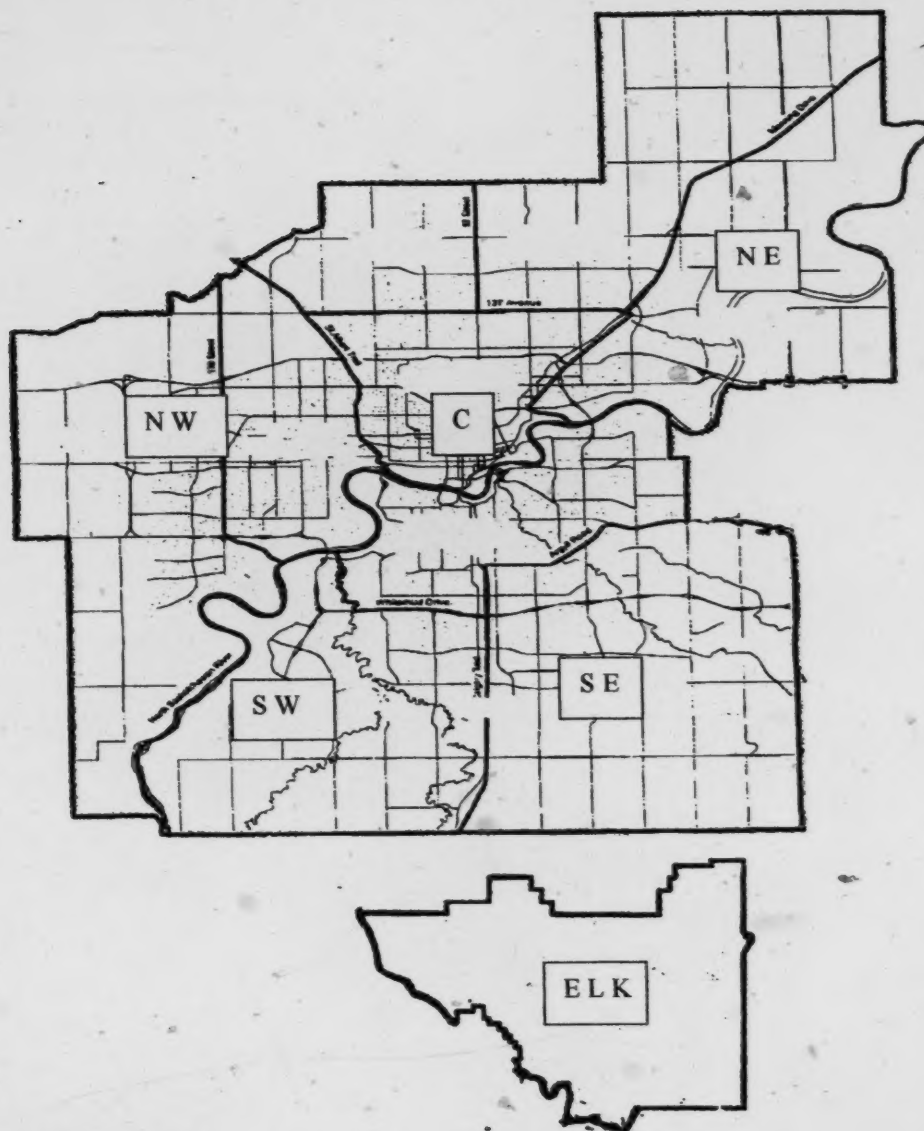
Random sampling techniques were employed in all sample selections (baseline, subset and space sample selections). Simple random sampling is a method of selecting a sample population from the total population such that any of the total population has an

equal chance of being chosen (Cochran 1963). This was employed primarily to eliminate bias. Also, Berry and Lindgreen 1996 reported that random sampling techniques bound the sampling errors to a tolerance level while minimizing the number of samples.

3.5.1 Baseline Sample Population

The aim of this study was to determine a sample size primarily to provide baseline information for ventilation rates, CO, CO₂, relative humidity and temperature. In order to ensure a normal distribution, a minimum of 30 schools were required according to central limit theorem which states that if a set of random samples is obtained from a larger population, the sample mean tends towards normality as it increases from a minimum of 30 (Mosteller and Tukey 1977). Jhandri (2001) recommended that 20% of the total population was ideal to achieve a normal distribution. Based on a total population of 217 schools, baseline sample size was calculated to be forty-three (43) schools. This consisted of 32 schools from Edmonton Public Schools (EPS), 7 schools from Elk Island Public Schools (EIPS) and 4 schools from Elk Island Catholic Schools (EICS) (Appendix 6). The North West (NW), North East (NE), Central (C), South West (SW) and South East (SE) strata consisted of Edmonton Public Schools while Elk Island district (ELK) stratum comprised of Elk Island Public Schools and Elk Island Catholic Schools. In addition, two schools per stratum were selected as reserves in the event that any of the randomly selected schools in each stratum refused to participate in the study.

The baseline sample population comprising 20% of the total population was based on the geographical regions or zones depicted in Figure 9. The distribution of schools in the baseline sample population across six strata based on these geographical



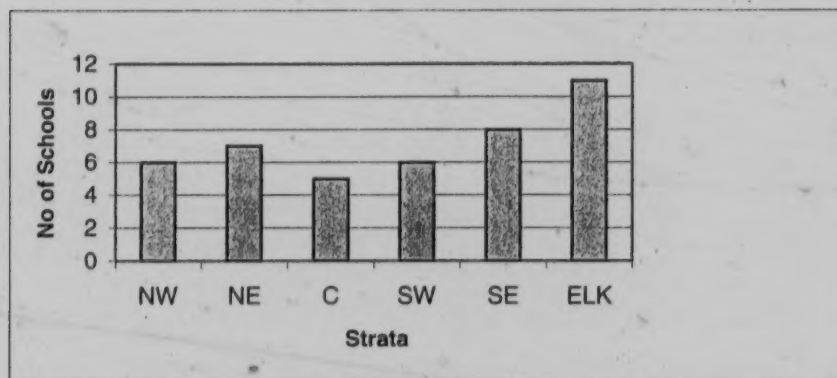
Strata/ Zonal Division

NE -North East
 NW -North West
 C -Central
 SE -South East
 SW -South West
 ELK -Elk Island District

Figure 9 Geographical Zones of School Population (Adapted from Johnson 2001, Lechelt 2001).

regions is provided in Figure 10.

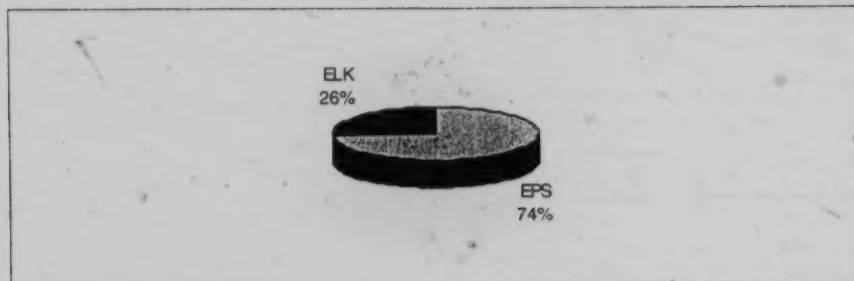
The resulting data representing baseline levels reported in this study were analyzed according to the first level stratification criterion (Geography) while the second level stratification criterion (water/no water damage) was ignored. This is because at the second level stratification, sample sizes were small and highly variable (Appendix 4). For instance, in the NW stratum, 9 schools have had no water damage compared to 39 schools that have had water damage in the past five years. Based on the 20% rule used to obtain the baseline sample, only one school without water damage would be selected compared to 8 schools with water damage in NW stratum as the baseline sample under the second level stratification. In order to avoid such small sample sizes resulting from deep stratification, analysis of the second level stratification data was ignored. Samples with water damage/without water damage were however represented in the baseline sample through the random sampling techniques employed.



NW-	North West	SW	-South West
NE	-North East	SE	-South East
C	-Central	ELK	-Elk Island District

Figure 10 Geographical Distribution of Sample Population.

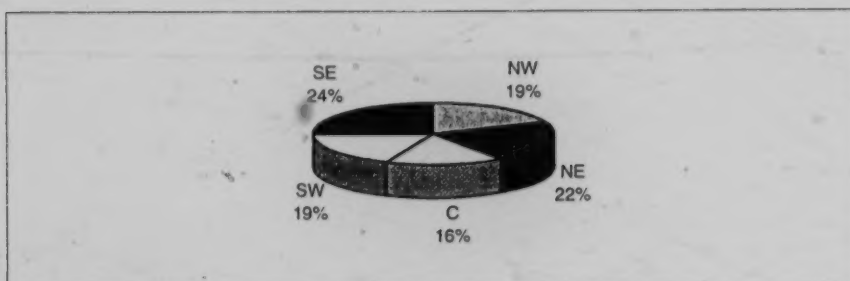
The distribution of the sample population according to the number of schools from each school board that participated in this study is seen in Figure 11. Edmonton



ELK -Elk Island District

EPS -Edmonton Public Schools

Distribution of Elk Island District and Edmonton Public Schools comprising the Sample Population.



NW -North West

NE -North East

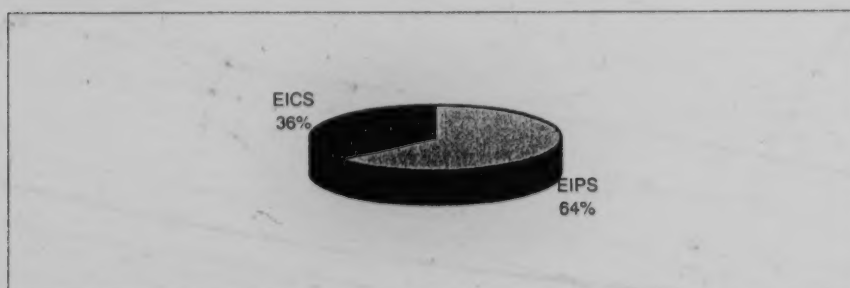
C -Central

SW -South West

SE -South East

Elk -Elk Island District

Strata Distribution of Edmonton Public Schools in the Sample Population.



EICS -Elk Island Catholic Schools

EIPS -Elk Island Public Schools

Distribution of Elk Island District Schools in the Sample Population.

Figure 11 Distribution of Sample Population based on School Boards comprising 20% of Total Population.

Public School Board (EPSB) made up 74% of the sample population while 24% was made up of schools from Elk Island district. The percentage of the sample

population from EPSB was distributed in 5 strata (NW, NE, C, SW and SE) while the percentages of sample population from ELK (Elk Island district) were distributed as 64% from Elk Island Public Schools (EIPS) and 36% from Elk Island Catholic Schools (EICS).

3.5.2 Subset Sample Population

This population was generated to allow critical analysis of factors that may influence CO₂, CO, temperature and relative humidity levels in the indoor environment. Sample sizes of between eight to ten schools were randomly selected for each subset (Appendix 7). Selected schools had to meet certain requirements of the subset otherwise they were rejected. Several factors were included in the subset study however only CO₂ variability within Space and CO₂ decay subsets were targeted.

3.5.2.1 Within Space Variability

Homogenous mixing of air within a space is generally assumed but studies show that room air may not be uniformly mixed due to convective air currents, stagnant air near walls and short-circuiting of some ventilation systems (Croome and Roberts 1981, Hanson and Burroughs 1998, Hines et al. 1993, Berglund and Cain 1989). Berglund and Cain (1989) reported that it takes approximately three (3) hours for spaces to attain uniformly mixed conditions. The sample population in this subset provided relevant data to establish whether air in occupied spaces was uniformly mixed or not. This was achieved by investigating the variability of CO₂ concentration in three locations within randomly selected spaces.

3.5.2.2 *CO₂ Decay*

CO₂ concentration in spaces has been related to the efficiency of ventilation systems and air exchange rates in classrooms (Chang and Lee 1998, Bayer 2000). Based on the principle of tracer gas measurements established by the American Society for Testing and Materials (ASTM), the rate at which CO₂ concentration diminishes over time in an unoccupied ventilated space has been used to obtain quantitative measurements of air exchange rates (Chang and Lee 1998, Modera and Persily 1993). This subset provided the means in which CO₂ decay trends in schools was observed. It also facilitated the comparison between air exchange rates obtained from CO₂ decay method and direct measurement of air velocities (described later).

3.5.2.3 *Seasonal Variability*

Bayer (2000) reported the effects of seasonal changes on indoor mould levels but this was not a target of the study. However, the effects of seasonal changes on indoor occupant comfort were relevant to this study. These effects are significant when considered for both summer and winter conditions because ASHRAE comfort standards (ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy) were based on winter and summer conditions. In this study field sampling of selected schools was conducted in the fall and winter seasons; summer was not represented. Therefore this subset (seasonal variability) was ignored.

3.5.2.4 *Within Phase Variability*

This subset examined the variability of targeted parameters (CO₂, CO, temperature and relative humidity) within each phase of building structures represented in the subset sample population. The phases identified were permanent, portable and pod. Leaderer et

al. (1985) reported that there are significant differences in ground temperature for different types of building structures however, floor and wall temperatures required to properly analyze this variability were not collected in this study.

3.6 Room/Space Selection

As clearly defined by the overall objective and funding of this research, only classrooms were targeted by this study. This involved the exclusion of gymnasium, washroom, music room etc. It was also mandatory that a space be occupied during sampling as defined by the ASHRAE procedure for ventilation for acceptable indoor air quality (ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality). Three spaces in each school were randomly chosen for field sampling for the following reasons: First, logistics reasons dictated three as the optimal sample size and second, in the event of instrument failure, sampling could be repeated.

3.7 Sampling Schedule

Several sampling scenarios were considered in order to determine the most efficient and cost effective design that met the objectives of the three research studies making up the overall study. Three sampling rounds were initially considered as September/October, December/January and March/April. However, the experimental design was modified to include two rounds because this enabled linear interpretation of data, while three rounds would require data interpretation as an incomplete quadratic design (Prasad 2000). Further more, two out of three rounds fell in the same season, which may constitute redundancy of data.

Round 1 and round 2 sampling were thus designated for October/November 2001 and January/March 2002 respectively. A sampling schedule (Appendix 8) was

employed in all school categories. Slight changes were incorporated due to teachers' preferences as to sampling periods in order to avoid disturbance to class. When a central HVAC was encountered in a school, only one central air-handling unit (AHU) serving selected spaces was inspected. Unit ventilators were sampled in all three selected classrooms in each school.

CHAPTER FOUR

4.0 MATERIAL AND METHODS

There are unique challenges existing in developing a database of IAQ parameters and standardized protocols due to limitations of measurement tools and limited access to ventilation facilities. Through on site assessment, practical and reliable procedures for making field measurements can be developed. This will form a basis for a range of engineering applications and provide useful information for school boards to assess and make strategic decisions regarding the IAQ conditions in schools.

4.1 Participant Recruitment and Consent

Participant recruitment took the form of a written document. Information sheets (Appendix 9) were sent to Edmonton Public School Board (EPSB) and Elk Island Public School Board. This ensured that each school board was informed of the names of schools selected to participate in the study. The availability of a facility personnel was requested from each school board through a "Facility Response Form" (Appendix 10). This ensured that names and phone contacts were established between facility personnel and field investigators. The facility personnel were required to assist in locating and providing relevant information regarding HVAC systems during walk through inspections.

School principals were informed of the study and proposed sampling dates through a "Principal Information Sheet" (Appendix 11). It assured principals of the non-intrusive nature of the study and provided the medium through which field investigators were introduced to school principals prior to sampling. Further more, it served to prepare

school heads for the arrival of field investigators. Two weeks before sampling commenced, schools were contacted by telephone to confirm sampling appointments.

In order to increase public awareness regarding this study, a news bulletin (Appendix 12) outlining the reasons for the study was published approximately one week prior to the first sampling date. This summarized the reasons of the study, the nature of samples to be collected from schools and introduced Capital Health Authority, EPSB, EIPS, EICS and University of Alberta graduate students as persons conducting the study. It also informed the public of the benefits to the community as well as emphasized that the study was in aid of proactive management of IAQ in schools. This information sheet was also sent to parents through their wards to alleviate any anxiety regarding the study.

The consents of the heads or principals of randomly selected schools (representing the baseline sample) were obtained through a "Principal Response and Consent Form" (Appendix 13). This requested a written consent of school principals and ensured that schools were scheduled for sampling within the convenience of both participants and field investigators. It also served as a means of obtaining the blueprints of each participating school in order to match spaces and types of ventilation systems against specific phases of building structures. The principal response and consent form was another HREB requirement.

4.2 Questionnaires and Field Surveys

Questionnaires are useful information gathering tools and have been used as indirect methods for measuring exposure by identifying physical characteristics of the indoor environment (NAS 1991). The National Institute of Occupational Safety and Health (NIOSH) reported that when questionnaires are administered prior to an initial

visit, results obtained facilitated the development of a more effective strategy in managing the specific IAQ problem and investigators' time on site was more effectively used (Hanson and Burroughs 1998). Several studies have employed questionnaires and surveys as preliminary investigative methods for identifying IAQ problems in spaces (Hanson and Burroughs 1998, Chang and Lee 1998 and Canadian's National Centre for Occupational Health and Safety (CCOHS 1999). Qualitative walk through surveys are a proven method of preliminary inspections of HVAC systems (USEPA 2000).

Questionnaires were developed using previous studies in IAQ (Hanson and Burroughs 1998, Kindzierski et al. 2000) as templates. The contents were defined from literature reviews, and evaluation of qualitative walk through inspections of ventilation facilities (Hanson and Burroughs 1998, CCOHS 1999, Dols and Persily 1993). Suggestions and input based on experiences of the steering committee members and the research supervisor were significant contributors to the realization of the first questionnaire. Subsequent questionnaires were developed and standardized from issues resulting from the first questionnaire.

An interview format was used in all questionnaires and surveys used. Questions asked were simple, explicit, user friendly and at reading level tailored to the participants. The questionnaires ensured some prior knowledge about the population, assisted in defining complaints and determined if IAQ problems were localized. Information obtained from administered questionnaires provided relevant information used in the experimental design of this study. It also identified relevant characteristics regarding selected spaces and ventilation systems inspected. While prescreening, school maintenance history and screening questionnaires were administered prior to field sampling, HVAC and room surveys mostly served as a medium through which

qualitative inspections and assessment of both spaces and ventilation systems were carried out during field sampling.

4.2.1 Prescreening Questionnaire

A prescreening questionnaire (Appendix 14) was developed as part of the initial preparation for the commencement of the study. Subsequent questionnaires were improvements on the prescreening questionnaire. It was completed by the facility personnel of participating school boards and provided information about the characteristics of the total population. The requested information included school categories, utilization rates, type of foundations, history of water damage, and types of ventilation systems.

4.2.2 School Maintenance History Questionnaire

This questionnaire was developed to provide information about the maintenance history of schools. Based on a five-year history plan, information was requested on incidence of water damage, renovations/upgrades and air balancing (Appendix 15). The facility personnel of participating school boards completed this questionnaire prior to field sampling.

4.2.3 Screening Questionnaire

This questionnaire was focused on individual school characteristics regarding types of ventilation systems, phase description and evidence of water damage (Appendix 16). This questionnaire provided information about the types of HVAC systems operating in a school. Phase description ensured that evidence of water damage resulting in IAQ issues could be isolated to their appropriate phases. The Screening questionnaire

contributed to the development of the experimental design and was completed by the facility personnel prior to field sampling.

4.2.4 Heating Ventilation and Air Conditioning (HVAC) Survey

A HVAC survey was targeted towards the types of ventilation systems (unit and central ventilation systems) investigated in schools. It provided relevant information concerning particular ventilation systems serving selected spaces (Appendix 17). Information provided by this survey included conditions of heating coils, filters and general conditions of HVAC systems. Field investigators in the company of facility personnel administered this survey during HVAC walk through inspection exercises.

4.2.5 Room Survey

This questionnaire was developed to capture conditions of different spaces in terms of size variations, the presence of plants, number of occupants present at time of sampling, evidence of water damage, etc. (Appendix 18). It was administered by field investigators and was instrumental in data analyses.

Despite the usefulness of questionnaires, some limitations also exist: Questionnaires and surveys may be a source of bias. Such bias may be due to error of measurement or non-response based on individual interpretation of the questions asked (WHO 1995). Cochran (1963) reported that bias in surveys distorts the probability of confidence limits in interpreting results. Questionnaires may exhibit lack of validity when some sources of exposures are excluded (WHO 1995). Questionnaires are usually small documents and in an attempt to make them user friendly some relevant information may be excluded.

The validity of a questionnaire can be confirmed by comparison between the data obtained from the questionnaire and data from other sources (WHO 1995). Pretesting of a questionnaire is reported to be a method of identifying bias (NAS 1991). The prescreening question used in this study also served as a pretest. This ensured that subsequent questionnaires provided comprehensive information about the conditions of selected schools.

4.3 Air Quality Monitoring

4.3.1 Selection of Air Monitoring Instruments

Choosing the most appropriate sampling instrument for this study depended on research objectives, budget, logistics and method of operations. Research objectives specified that air sampling be conducted in order to obtain airflow rates, CO₂, CO, relative humidity and temperature of spaces. As reported by Calgary Health Services (1993), three methods of air sampling are instantaneous measurements, time weighted averages (TWA) and continuous measurements. Instantaneous measurements are taken over a short period and used to confirm the presences of specific contaminants in a sample. Time weighted average (TWA) yields mean concentrations of parameters over a period of time. Continuous measurements determine both peak concentrations and time weight average concentrations over a period of time.

Both TWA and continuous measurements were required to fulfill the objectives of this study. TWA measurements over 15 minutes were adopted for sampling of targeted parameters while continuous sampling became useful for taking concentrations of CO₂ over 6 hours in order to observe peak periods and establish classroom load profiles. Continuous sampling measurements were also used for CO₂ decay measurements.

The available budget for the project meant that, the efficiency of proposed instruments had to be considered with cost as well as manufacturer's delivery times. Since the whole project had three components, it was more cost effective to select a single instrument that had the capability to measure several parameters.

Logistics and mode of operation also played a large consideration. The sampling design required frequent transportation of air sampling instruments from space to space. A portable and compact air sampler would be less problematic in moving from space to space than a bulky equipment.

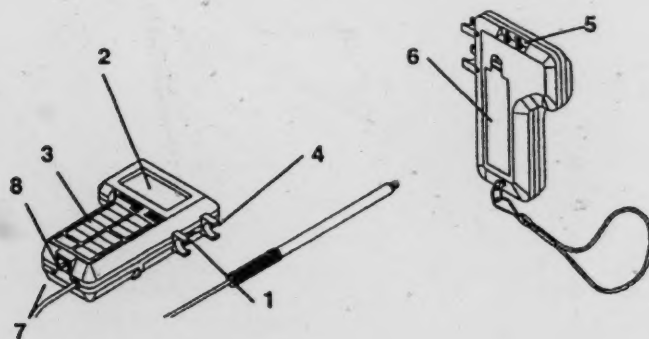
Air sampling was conducted indoors while classes were in sessions. This required the proposed instruments to be quiet and non-intrusive in their mode of operations. Outdoor samples were also conducted during winter therefore the air samplers chosen would be able to withstand low winter temperatures.

Based on the above factors, a Velocicalc Plus Air Velocity Meter was used to obtain air velocity measurements of outdoor air supplied into spaces while two Q-track Air Meters were used for CO, CO₂, temperature and relative humidity measurements within selected spaces. In addition, an Alnor Balometer Air Balancing Instrument facilitated the development of a linear model used in correcting calculated airflow rates obtained through air velocity measurements. Both instruments (Velocicalc Plus Air Velocity Meter and Alnor Balometer Air Balancing Instrument) were used in obtaining airflow measurements from 17 randomly selected diffusers. These two datasets obtained were used to obtain a linear model through linear regression analysis.

4.3.2 Velocicalc Plus Air Velocity Meter

Velocicalc Plus Air Velocity Meter model 8345 was used for air velocity measurements. It has been widely applied in systems air balancing, HVAC system

performances, energy audits, etc. (Awbi and Allwinkle 1986, Chang and Lee 1998, Modera and Persily 1995, Dols and Persily 1993). The Velocicalc Plus Air velocity Meter consists of a housing and a probe (Figure 12).



1. Backlight Switch
2. Display
3. Keypad
4. Probe Mounting Clips
5. Pressure Measurement Ports
6. Battery Access cover
7. AC adaptor port
8. Printer output/ Communications port

Figure 12 Velocicalc Plus Air Velocity Meter (Adapted from ASHRAE 1985, Handbook of Fundamentals).

The housing contains a sampling function, which allows for easy recording of either single or multiple measuring points and displays time weighted average values. The statistics function displays average, maximum and minimum values for continuous

data logging of air velocity between 0 to 30 m/s with an accuracy of ± 0.15 m/s (ASHRAE 1985, Handbook of Fundamentals). The extendable probe is 0.94 m in length. It consists of an air velocity sensor and a temperature compensation sensor.

4.3.2.1 *Theory of Velocicalc Plus Air Velocity Meter*

Velocicalc Plus Air Velocity Meter is a constant temperature thermal anemometer operating on the basic principle of the Wheatstone bridge circuit (Figure 13) (Croome and Roberts 1981). The air velocity and temperature sensors form two opposite ends of a Wheatstone bridge while an amplifier ensures that the voltage at points "A" and "B" are equal. When the probe is inserted into air streams, air flowing past the velocity sensor "A" tends to cool the sensor and thus reduce the resistance of the temperature sensor "B".

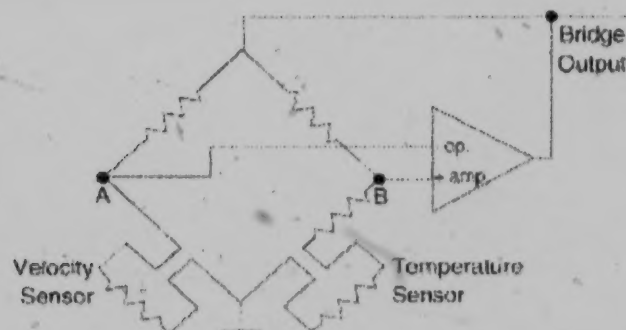


Figure 13 Wheatstone bridge Circuit Diagram (Adapted from ASHRAE 1982, Handbook of Applications).

The operational amplifier responds by supplying more power to the top of the bridge to maintain equilibrium voltage at points "A" and "B". As more air flows past the velocity sensor A, more power is required to maintain a balanced bridge between

the velocity and temperature sensors. The power supplied to the top of the wheatstone bridge is related to the velocity of the air flowing past the velocity sensor "A".

4.3.2.2 Air Velocity Measurements

Air velocities from air ducts are impacted by air densities and areas of the conduit (Croome and Roberts 1991). Based on the principle of conservation of mass and the assumption that air is incompressible, the continuity equation (Equation 5) has been used in several studies to express the relationship between air velocities and the duct areas (Goodfellow 1988, Hanzawa et al. 1987, ASHRAE 1985, Handbook of Fundamentals). Simply put, the principle of conservation of mass states that matter cannot be created or destroyed; it can only change its form therefore the flow of air entering a duct per unit time is equal to the amount leaving the duct per unit time plus any increase in the control volume (Awbi 1991).

When air is assumed to be incompressible and the flow in the duct is at a steady state, then the amount of air entering the duct per unit time is the same as the amount of air leaving the duct per unit time (Figure 14).

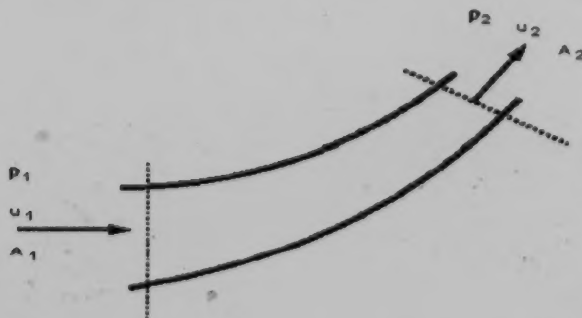


Figure 14 Schematic of an Air Duct (Adapted from Croome and Roberts 1981).

For a one dimensional flow,

Mass flow of air $m = \rho AV$

When airflow is at steady state, mass of air entering the air duct per unit time at point 1 and the mass of air leaving point 2 per unit time are constant.

$$\rho V_1 A_1 = \rho V_2 A_2 = m = \text{constant}$$

When air is assumed as incompressible, the density is the same everywhere in the duct, therefore:

$$V_1 A_1 = V_2 A_2 = Q$$

Equation 5

Where

Q = airflow rate, m^3/hr

V_1 and V_2 = air velocities at points 1 and 2, m/s

A_1 and A_2 = cross sectional area of the duct at points 1 and 2, m^2

ρ = air density, kg/m^3

Equation 5 represents the flow characteristics in the duct for an ideal case. In reality, airflow in the duct is subject to pressure fluctuations, which cause air turbulence and result in higher velocities usually at the center of the duct (ASHRAE 1985, Handbook of Fundamentals).

Three methods for obtaining airflow rates are airflow horn, the use of duct size with an optional K factor and duct transverse (ASHRAE 1982, Handbook of Applications 1982, USEPA 2000). Airflow horn has been used to determine airflow from diffusers, fans or similar air circulation inlets or outlets (Croome and Roberts 1981). However, this method of instrument was not employed in this study because the airflow horn is an accessory device and will always be used with another air velocity

meter to take airflow rate measurements. Also, the accuracy of air horn depends largely on the accuracy of the air velocity meter used in conjunction with the airflow horn (ASHRAE 1982, Handbook of Applications).

The use of a duct size and an optional K factor is another method used to obtain airflow rate measurements when access to air ducts are limited (USEPA, 2000). K factors are constants used to correct the occurrence of air turbulence in air ducts. Different factors are usually specified for different types of air terminal devices or diffusers. The unavailability of appropriate K factors prevented the use of this method in this study.

Several studies have reported the duct transverse as the most efficient method of obtaining air flowrates from air ducts (USEPA 2000, Gage 1971 and ASHRAE 1982, Handbook of Applications). This may either be single point measurements or a full transverse. For single point measurements in circular ducts, USEPA (2000) recommended that air velocity measurements be taken at least 7.5 duct diameters downstream and at least 3 duct diameters upstream from any turns or flow obstructions. For rectangular ducts, the same method is used with an equivalent duct diameter (Equation 6) expressed as:

$$\text{EquivalentDiameter} = \sqrt{\frac{4HV}{\pi}} \quad \text{Equation 6}$$

Where

H = horizontal duct dimension

V = vertical duct dimension

π = 3.14

Air turbulence in the center of the duct is accounted for by multiplying velocity point measurements by a factor of 0.9. This achieves an accuracy of between ± 5 to 10% (ASHRAE 1982, Handbook of Applications).

A full transverse based on the log-Tchebycheff method is preferred for greater accuracy (Hines et al. 1993, USEPA 2000, Moschandreas and Relwani 1990). This involves drilling 3 holes in the duct at an angle of 60° from each other. A minimum of 25 points must be measured in order to obtain a good average (USEPA 2000). The flow rate is obtained by multiplying the average velocities by the duct areas.

Duct transverse was eliminated as a procedure for obtaining airflow rate measurements in this study due to limited access to air ducts. Also, the time allotted to the study did not allow for the extra time required to transverse all the ducts leading to the spaces sampled. Furthermore, the project budget did not include the extra man-hours required by the facility personnel to open up the ducts.

In this study, airflow rates were obtained using the continuity equation (Equation 5). The Velocicalc Plus Airflow Meter was used to take single point air velocity measurements (reported as TWA velocities) at the base of diffusers and air grilles. Airflow rates were then obtained by the multiplication of TWA velocities and duct or grilles area (Equation 5). With the aid of Alnor Balometer Air Balancing Instrument, correction for calculated airflow rates (obtained from air velocity measurements) was also developed to correct for any fluctuations in air ducts and for any influences that may results from taking air velocity measurements at the base of diffusers and air vents instead of inside air ducts. In this study, the Alnor Balometer was used as a calibrating tool. Airflow measurements obtained from the Alnor Balometer were considered

accurate and used as a standard for correcting the calculated airflow measurements obtained from the Velocicalc Plus Air Velocity Meter through a regression analysis.

4.3.3 Q-track Air Meter

The Q-track model 8551 (Figure 15) is an air quality-monitoring instrument with capability to simultaneously measure carbon dioxide, carbon monoxide, temperature and relative humidity. Its main compartments are a housing and a probe. The housing has external dimensions of 1.28 m by 2.19 m by 0.456 m. It contains different functions for measurement of the aforementioned parameters.

The operating range of the Q-track is between 5 to 45°C which renders it ineffective during winter conditions (ASHRAE 1982, Handbook of Applications). It has the capability to measure 63,000 data points or 10 days of logging parameters once a minute. It also has the capability of data logging intervals up to one hour (TSI 2002). This unique feature ensured the 6 hours continuous monitoring of parameters conducted in order to observe peak conditions. It also facilitated 3 hours continuous logging of CO₂ decay.

The extendable probe is 1.98 m in length with a probe diameter of 0.23 m. The probe contains individual sensors for simultaneous measurement of CO₂, CO, temperature and relative humidity.



1. Display
2. Keypad
3. External Power Socket
4. Data Port RS-232
5. Probe Mounting Clips
6. Display/Keypad Lock out switch
7. Location of Humidity sensor
8. Location of temperature Sensor
9. Location of CO₂ Sensor
10. Probe Handle
11. Battery Access Cover
12. Wrist Strap

Figure 15 Q-track Air Meter (Adapted from ASHRAE 1982, Handbook of Applications).

4.3.3.1 CO₂, CO, Temperature, and Relative Humidity Measurements

The carbon dioxide sensor measures CO₂ concentrations in the surrounding air based on non dispersive infrared (NDIR) technique (Croome and Roberts 1981). CO₂ molecules absorb light at a specific wavelength of 4.26 μm , which is in the infrared range. The filter in front of the CO₂ sensor in the probe eliminates all light from the

surrounding environment except the 4.26 μm wavelength that CO_2 molecules can absorb. Since other gas molecules do not absorb light at this wavelength, only CO_2 molecules affect the amount of light from the indoor environment reaching the detector. The intensity of 4.26 μm light that reaches the detector is inversely related to the concentration of CO_2 in the sensing chamber. As the concentration of CO_2 increases, the intensity of light striking the detector decreases. Beers' law (Equation 7) describes the exact relationship between infrared (IR) light intensity and CO_2 concentration.

$$I = I_0 e^{-kp}$$

Equation 7

Where

- I = intensity of light striking the detector
- I_0 = measured signal with 0 ppm CO_2
- K = system dependent constant
- P = CO_2 concentration, ppm

The CO_2 sensor measures CO_2 concentration between the ranges of 0 to 9000 mg/m^3 (0 to 5000 ppm) with a response time of 20 seconds and an accuracy of $\pm 90 \text{ mg}/\text{m}^3$ (50 ppm) (Croome and Roberts 1998).

The temperature sensor is made up of a semi conductive material and its operation is based on the principle that the resistance of the material changes with temperature (Awbi 1991). The resistance of the semi conductive material in the temperature sensor decreases with increasing sensor temperature. It measures operative temperatures within the range of between 0 to 50°C with an accuracy of $\pm 0.6^\circ\text{C}$ and a response time of 120 seconds (TSI 2002).

The relative humidity sensor is a thin film sensor which measures the RH in the surrounding air in the range of 5 to 95% RH with an accuracy of $\pm 3\%$ RH and a response time of 20 seconds (Croome and Roberts 1998).

The CO sensor measures CO in the range of 0 to 575 mg/m³ (0 to 500 ppm) with an accuracy of ± 3.5 mg/m³ (3 ppm) and a response time of 60 seconds (Croome and Roberts 1998).

4.3.4 Alnor Balometer Air Balancing Instrument

The Alnor Balometer is a hood designed to capture rapid and accurate measurements of air distribution in heating, ventilation and air conditioning systems (Croome and Roberts 1981). It consists of two main compartments, namely the hood and the velometer. The hood comes in several diffuser sizes designed to cover the total diffuser area during measurements. The standard size is a 0.608 m by 0.608 m (2 ft by 2 ft) hood although other sizes are available. During measurement, air is directed past a manifold, which senses the flow at multiple points spread across a carefully sized area.

The velometer is the heart of the balometer and consist of volumetric scale in both English and Metric units. It is capable of measuring air flowrates up to 3338 m³/hr (2000 cfm) (ASHRAE 1982, Handbook of Applications). A single knob direction and range selection unit serves as a control when used for either supply or return diffusers.

4.3.4.1 *Development of a Linear Model for Correction of Calculated Airflow Rates from Velocicalc Plus Air Velocity Meter*

In this study, the Alnor Balometer was used to correct calculated airflow rates obtained through air velocity measurements with the aid of Velocicalc Plus Air velocity

Meter. The Alnor Balometer measures average airflow rates directly from both supply and return vents and eliminates the need for K factors or duct transverse (Dols and Persily 1993). Based on tests conducted by the National Environmental Balancing Bureau (NEEB) at the University of Tennessee, it was determined that the capture hood (Alnor Balometer) meets and exceeds published specifications to an accuracy of 1.39 to 3.34% when used in well defined flow precision nozzles specified by the American Society of Mechanical Engineers (ASME) (Hines et al. 1993).

The capture hood has been validated for the calibration of a thermal anemometer such as the Velocicalc Plus Air Velocity Meter (Goodfellow 1988, USEPA 2000, Dols and Persily 1993, Modera and Persily 1995). In this study, seventeen (17) diffusers with the same shape and dimensions (0.608 m by 0.608 m) were randomly selected from 43 schools comprising the baseline sample population. The selection of spaces was consistent with the baseline sample selection i.e. three spaces per school. Variations exist in the type of ventilation systems (HVAC or Unit Ventilation Systems) present in selected spaces therefore each space selected had to meet the necessary requirement which is the presence of 0.608 m by 0.608 m rectangular air diffusers. Air velocities were then measured from each diffuser with the Velocicalc Plus Air Velocity Meter and converted to airflow rates by applying the continuity equation (Equation 5). The Alnor Balometer was also used to measure airflow rates directly from the same diffusers. A linear regression model was then developed using both sets of data.

Regression analysis is an increasingly powerful tool used in analysis of environmental field data (Mosteller and Tukey 1977). Uncertainty in velocity measurement was applied to the dependent variable (capture hood airflow rate measurements) while the Velocicalc measurements were considered as the independent

variable. This distinction between dependent and independent variable was relevant because if the variables were interchanged, the resulting fit would be different (Mosteller and Tukey 1977). With the aid of excel spreadsheet, a linear regression model was developed. All the calculated airflow rates obtained from the Velocicalc Plus Airflow Meter in this study were corrected using the linear regression model.

4.4 Field Sampling Procedure and Conduct Protocol

The field sampling procedure used in this study involved the use of Velocicalc Plus Air Velocity Meter and Q-track Meter. The Velocicalc Plus Air Velocity Meter was used to measure air velocities of outdoor or ventilation air supplied to randomly selected spaces through air diffusers and air grilles while the Q-track Meter was used to obtain CO, CO₂, temperature and relative humidity levels in randomly selected spaces. Field sampling consisted of outdoor and indoor sampling of the aforementioned parameters. Outdoor sampling of CO, CO₂, temperature, and relative humidity were used as a control in monitoring indoor levels of the same parameters. This was not possible at temperatures below 5°C which is the operating limits of air samplers (Velocicalc Plus Air Velocity Meter and Q-track Meter) used in this study.

A conduct protocol (Appendix 19) was developed to ensure that field investigators observed similar protocols in all the schools investigated. This specified whom to see in the school at the resumption of each sampling day as well as the order in which sampling activities were carried out.

The indoor sampling procedures for measurement of both IAQ parameters (CO and CO₂) and comfort factors (temperature, relative humidity and airflow rates) were essentially the same for both sampling rounds (round 1 and 2). A sampling protocol (Appendix 20) was developed to ensure that the same sampling procedures for both

indoor and outdoor measurements of CO, CO₂, temperature, relative humidity and airflow rate were followed for all randomly selected spaces. This sampling protocol was followed as concisely as possible. A few changes were incorporated during field sampling to account for variations in sizes, shape and arrangement of classrooms.

Standard operating procedures (SOP) for Velocicalc Airflow Meter, Q-track and Alnor Balometer Air Balancing Instrument (Appendix 21) were developed to ensure the elimination of bias from three field investigators using the same instrument at different times. Each SOP was followed concisely during sampling of each randomly selected space to ensure accuracy of the results reported. The Velocicalc Plus Air Velocity Meter was used to obtain 15 minute samples of air velocities at the base of diffusers and air grilles due to limited access to air ducts. The probe was placed at the base of each diffuser such that the tip of the probe containing sensors was vertical to the air stream. At least four point measurements were taken at each diffuser. Using Equation 5, a TWA velocity for each diffuser was multiplied by the duct area to obtain the airflow rate of each diffuser. The addition of the airflow rates from each diffuser or supply grille in a space represented the total air supplied to that space. Based on ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, outdoor airflow rate supplied to each space was obtained by subtracting the combination of return and exhausted airflow rates from air supplied to that space. This eliminated recirculated air and ensured that ventilation results could be compared to ASHRAE Standard 62-2001, specifications for outdoor air supplied.

The Q-track was used for both baseline and subset samples. Baseline data were obtained by taking 15-minute time weighted averages for CO₂, CO, RH and operative temperatures as indicated in the sampling protocol (Appendix 20). As part of the subset samples, "Within Space" measurements involved taking 15 minutes TWA of the

aforementioned parameters at three locations in a total of 9 spaces identified as "Front Right" (FR) or "Front Left" (FL), "Centre Right" (CR) or "Centre Left" (CL), "Back Left" (BL) or "Back Right" (BR). Depending on the shape of the classroom and the reference point (black board), at least one location each was sampled from the front, centre and back locations of each classroom in the subset sample.

Continuous measurements of 15-minute time weighted average CO₂ concentrations were taken from eight randomly selected spaces making up the "CO₂ decay" subset. The Q-track was set up for 3 hours after students had left the classrooms at the end of a school day. It was mandatory that the spaces sampled were occupied for normal classroom activities during the day and the ventilation system was still operating during the sampling period.

Continuous CO₂ concentrations were also monitored for six hours in selected classrooms commencing when students resumed classes in the morning. At least one space per school was monitored in order to observe the space load profile and peak conditions of CO₂, temperature, CO and relative humidity levels.

The field log data obtained for 43 schools (baseline sample) are provided in Appendix 22. This consisted of field data for air velocities, CO, CO₂, temperature and relative humidity levels for 3 spaces per school as defined by the experimental design of this study. The linear regression analysis (Appendix 23) was used to obtain a linear model that was applied to all calculated airflow rates obtained from the Velocicalc Plus Air Velocity Meter. The linear regression analysis was developed through the use of excel spreadsheet.

An IAQ Advisory Form (Table 5) was developed as the protocol for reporting levels of targeted parameters that constituted a danger to the occupants of the school. This was addressed to the representative from the school board of the school concerned

who took the appropriate action to report such level. As regards to parameters targeted by this study, the IAQ advisory form was only used once to report a carbon dioxide level of 6561 mg/m³ (3645 ppm). While this CO₂ level did not constitute a danger to students, it had to be reported to the appropriate school board representative in line with the IAQ standard and conduct protocol employed in this study.

Table 5 IAQ Advisory

Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools, Elk Island Catholic Schools		
IEQ ADVISORY		
School:	Today's Date:	Date of Observation:
Distribution:	- Principal Lisa Johnston - Personnel (EPSB) Dale Lechelt - Personnel (EISB) Steve Hayes - Personnel (EICS)	
Principal Investigators:	Steven Probert - Indoor Air Specialist, Capital Health Authority Warren Kindzierski - Professor, Environmental Engineering, University of Alberta	

Description of IEQ Concern	Location of IEQ Concern	Action taken

4.5 Quality Assurance and Quality Control Measures (QA/QC)

Quality assurance and quality control measures were incorporated at various stages of this study to ensure the precision of results reported. The two air monitors (Velocicalc Plus Air Velocity Meter and Q-track Meter) were used for quality assurance and quality control. QA/QC was also achieved through adherence to sampling protocol.

Velocicalc Plus Air Velocity Meter was factory calibrated prior to the beginning of the study as only one calibration was required per year (TS1 2002). The Q-track was calibrated prior to each sampling round using pure nitrogen (0 mg/m^3 CO_2) and a known concentration of CO_2 (1800 mg/m^3). This ensured that measurements of parameters were accurate and instrument error was minimized.

The sampling protocol (Appendix 20) was also used as a QA/QC measure. It was strictly adhered to in order to minimize bias in sampling resulting from three investigators using the same instruments. Random sampling techniques were used in selection of samples (baseline, subset and space samples) in order to minimize bias and ensure that reported results were representative of IAQ conditions in schools.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

The environmental field sampling conducted in this study was constrained by several internal (gas cookers, thermostats, humidifiers, etc.) and external (increased ventilation rates from natural ventilation sources) factors. Therefore, outdoor and indoor levels for CO, CO₂, temperature and relative humidity obtained from ten (10) randomly selected spaces were analyzed in order to establish the influences of outdoor and indoor sources on indoor levels of targeted parameters. The classroom load profile or temporal trends for the aforementioned parameters were also determined from 6 hour continuous air monitoring.

Both baseline and subset data were analyzed in this study. The baseline data were analyzed according to geographical stratification (first level stratification) as defined by the experimental design. Water/no water damage (second level stratification) was ignored. This was because at the second stratification level, sample sizes were small and highly variable in comparison to the first stratification level. Subset data analyzed in this study were CO₂ variability in spaces and CO₂ decay. In addition, air exchange rates obtained from both CO₂ decay and from direct air measurements were compared under the subset analysis. It is worth noting that apart from outdoor control samples, all the reported results of parameters in this study were indoor levels.

5.1 Outdoor/ Indoor Levels

Outdoor samples were used as a control for indoor levels. These were achieved by taking both outdoor and indoor samples of CO₂, CO, temperature and

relative humidity levels from ten randomly selected spaces. The outdoor and indoor levels of the aforementioned parameters are presented in Table 6.

Table 6 Outdoor / Indoor Levels of Samples from Ten Randomly Selected Spaces.

Spaces	Outdoor Control Sampling			
	C O ₂ Conc. (mg/m ³)	CO Conc. (mg/m ³)	Temp °C	RH %
R1-NE-003	597	0	8	35.1
R1-NW-004	587	0	11	10.3
R1-E-012	615	0	8	32.6
R2-SW-005	623	0	9	41
R1-SE-006	565	0	0	60.7
R2-E-021	684	0	5	40.2
R1-NE-008	713	0	5	30.2
R1-SE-013	772	1	7	38.1
R1-SW-017	664	0	10	34.2
R1-SW-016	673	0	6	40.5

Spaces	Indoor Sampling			
	C O ₂ Conc. (mg/m ³)	CO Conc. (mg/m ³)	Temp °C	RH %
R1-NE-003	1637	0	22	25.5
R1-NW-004	1542	0	21	29.2
R1-E-012	1538	0	22	27.3
R2-SW-005	1788	0	21	31.2
R1-SE-006	2150	0	21	31.5
R2-E-021	1585	0	23	26.8
R1-NE-008	1990	1	21	26.0
R1-SE-013	1754	1	22	29.6
R1-SW-017	1907	0	22	24.2
R1-SW-016	2017	1	23	25.9

NW North West
NE North East
C Central
R1 Round 1
R2 Round 2
SW South West
SE South East
EIK Elk Island Schools

Several studies have reported that outdoor levels for IAQ parameters and comfort factors targeted by this study are usually lower than indoor levels (USEPA 2000, Kuo et al. 1982, Traynor 1987). The reasons given for higher indoor levels were attributed to indoor sources such as furnace heating systems, gas cookers, thermostats,

dehumidifiers and recirculation of indoor air (Giovoni 1991). Usually indoor comfort factors such as temperature and relative humidity reflect the outdoor climatic conditions at the beginning of the day before indoor sources are used to alter these factors to suit the comfortable range of indoor occupants (Potter and Booth 1994, Lugg and Batty 1998).

The descriptive statistics (Table 7) for the outdoor and indoor levels reported in Table 6 indicate that mean indoor levels for CO₂, CO and temperature data were higher than outdoor levels in ten randomly selected schools. In contrast, mean outdoor relative humidity levels were higher than indoor levels for the same schools. This may indicate outdoor climatic conditions at the time of sampling. The results for the median and maximum levels of CO₂ and temperature in indoor spaces were higher than the outdoor levels while the median and maximum levels for indoor relative humidity levels were lower than outdoor levels. The median and maximum levels of CO reported the same indoor and outdoor CO concentrations. This may indicate the condition of outdoor air at the time of sampling. Table 7 also suggests that indoor samples were variable in comparison to outdoor control samples as determined by the standard deviations. The variability in indoor levels suggests the influences of localized indoor sources rather than the ambient conditions outdoors.

Table 7 Descriptive Statistics of Outdoor control and Indoor samples for Ten Randomly Selected Spaces.

Parameter	Outdoor Control Samples (n= 10)				Indoor Samples (n=10)			
	Mean	Median	Max	Std. Dev.	Mean	Median	Max	Std. Dev.
CO ₂ (mg/m ³)	649	643	772	64	1791	1771	2150	218
CO (mg/m ³)	0.1	0	1	0.4	0.3	0	1	0.5
Temp. (°C)	7	8	11	3	23	22	23	0.8
Relative humidity (%RH)	36	37	61	12	28	27	31	3

Paired t-tests ($\alpha = 5\%$) were conducted to examine whether significant differences existed between outdoor and indoor levels of measured parameters. The results obtained (Table 8) show that there were significant differences between outdoor and indoor levels (i.e. $t\text{-stat} > t\text{-critical}$) for CO_2 and temperature levels. In contrast, outdoor and indoor CO and relative humidity levels indicated no significant differences (i.e. $t\text{-stat} < t\text{-critical}$). Significant differences suggest that indoor sources are the predominant contributor to indoor levels while lack of significant differences suggests outdoor sources as the predominant contributor to indoor levels.

Table 8 Comparison of Outdoor and Indoor levels of CO_2 , CO, Temperature and Relative humidity ($n = 10$).

Parameter	Statistical Measure	
	t-stat	t-critical
CO_2 (mg/m^3)	16.3	2.3
CO (mg/m^3)	1.7	2.3
Temperature $^{\circ}\text{C}$	14.5	2.3
Relative humidity %RH	2.2	2.3

5.2 Temporal Load Trends

Six – hour continuous air monitoring was conducted in at least one space per school in order to establish the load profile of the spaces based on activity patterns. For example, typical plots of 6-hour air monitoring of 3 spaces (Figure 16) show that the CO_2 peak periods were at approximately 11:30 am for most of the schools. Based on an evaluation of the classroom survey, it was established that these were usually during recesses, class changes or activities other than sedentary (i.e. when students were involved in activities that were not stationary). CO concentrations were non variable in two spaces and variable in one space. These suggest the operation of gas burners and or furnace heaters.

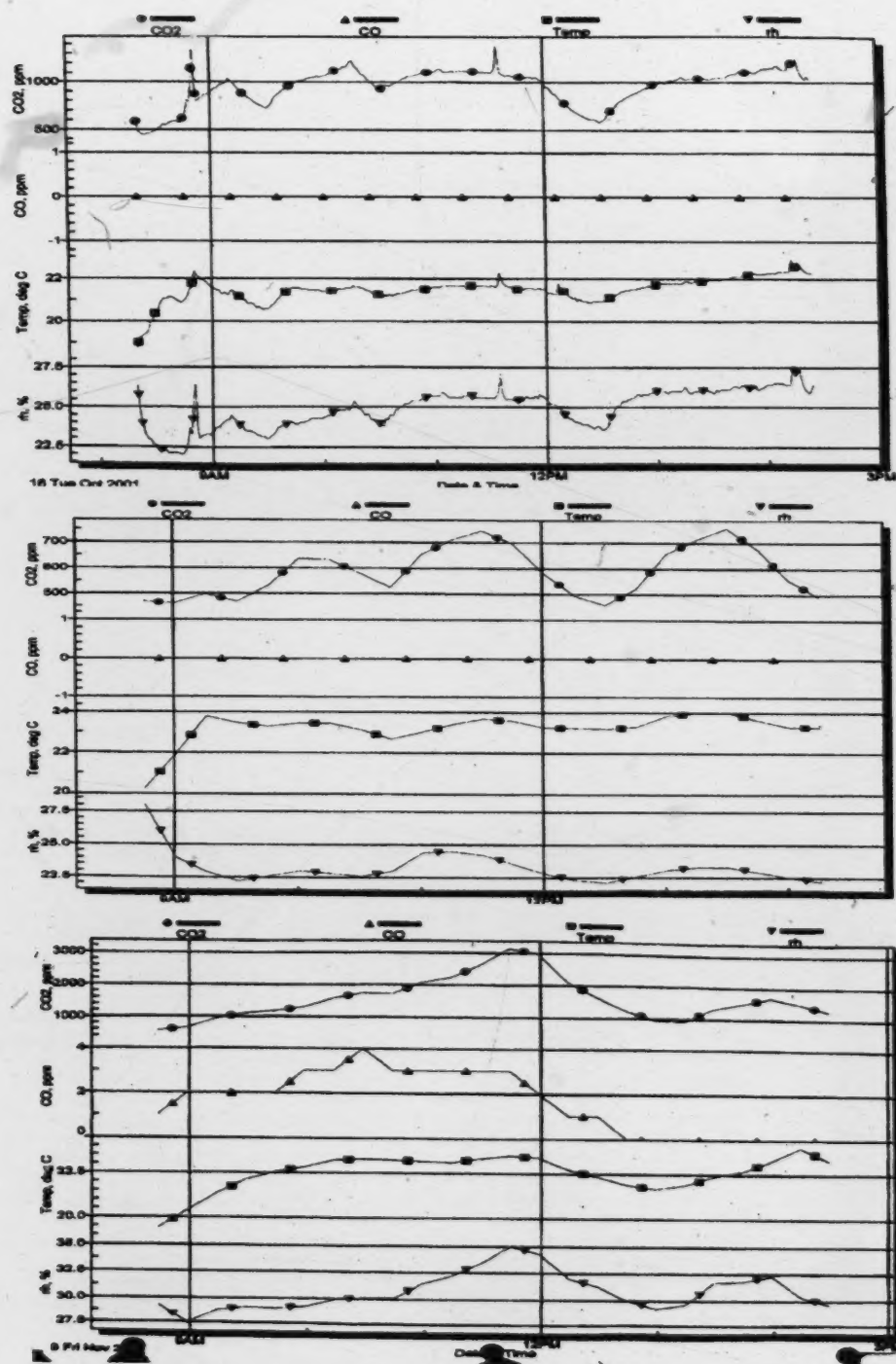


Figure 16 Temporal Trends for CO₂, CO, Temperature and Relative Humidity in three Spaces.

Temperatures were usually low at the beginning of the day but increased when the classrooms became occupied. An initial start up of ventilation systems or the operation of thermostats is indicated. Relative humidity levels indicated initial reductions and then became constant for the rest of the day. These suggest the effect of ventilation air on indoor relative humidity levels.

5.3 Analyses of Baseline Data

The analyses of baseline data were performed in order to achieve the overall objective of this study, which was to establish average indoor levels of CO₂, CO, temperature, relative humidity and ventilation rates in the sample population of 43 schools. As previously mentioned, the baseline data was analyzed according to geographical stratification while stratification based on water damage/no water damage was ignored. The baseline data reported in this study consisted of 129 spaces comprising three spaces per school with an average of 22 students per space. Baseline values reported for CO₂, CO, temperature and relative humidity levels were obtained directly from the air-monitoring instrument used (Q-track). In contrast, baseline data reported for ventilation rates were obtained through an indirect method. Due to inaccessibility to the air duct, the Velocicalc Plus Air Velocity meter was used to obtain air velocities from air ducts, which were then converted to airflow rates through the use of the continuity Equation 5. A linear regression model was also developed to correct the calculated airflow rates.

5.3.1 Correction of Calculated Airflow Rate Measurements

Environmental field measurements are usually characterized with a constant uncertainty such as a standard deviation (Mosteller and Tukey 1977). When

sufficiently large deviations occur, it is often compared to a Gaussian distribution, which justifies the use of least square regression analysis (Goodfellow 1988). Regression analysis was employed in this study to develop a linear model (Equation 8), which was used as a correction for all calculated airflow rates obtained from the Velocicalc Plus Air velocity Meter. From the result of the regression analysis (Appendix 23), 0.47 was obtained as the R^2 value of the regression analysis. This indicates the strength of the linear relationship and shows that 47% of variation in airflow rates from Alnor Balometer was explained by airflow rate from the Velocicalc Plus Air Velocity Meter. This linear model (Equation 8) was applied to all the calculated ventilation rates reported in this study.

$$Y = 0.55X + 167 \quad (R^2 = 0.47) \quad \text{Equation 8}$$

5.3.2 *Baseline Levels Based on Geographical Stratification*

Several studies have reported that in a stratified sampling design, the mean values of measured parameters (CO , CO_2 , temperature, relative humidity and ventilation rates) of individual stratum are approximately equal to the mean values of the same parameters in the total population (Smith 1986 and Mosteller and Tukey 1977). Descriptive statistics were derived in order to establish baseline levels for each targeted parameter according to individual stratum. The results are summarized (Table 9) using the mean and standard deviation, which ensured that the measures of central tendency as well as variation in the levels of parameters among the strata could be observed.

The distribution of indoor levels of CO₂, CO, temperature, relative humidity and ventilation rates in six strata designated as NW (North West), C (Central), SW (South West), SE (South East) and ELK (Elk Island district) were determined from

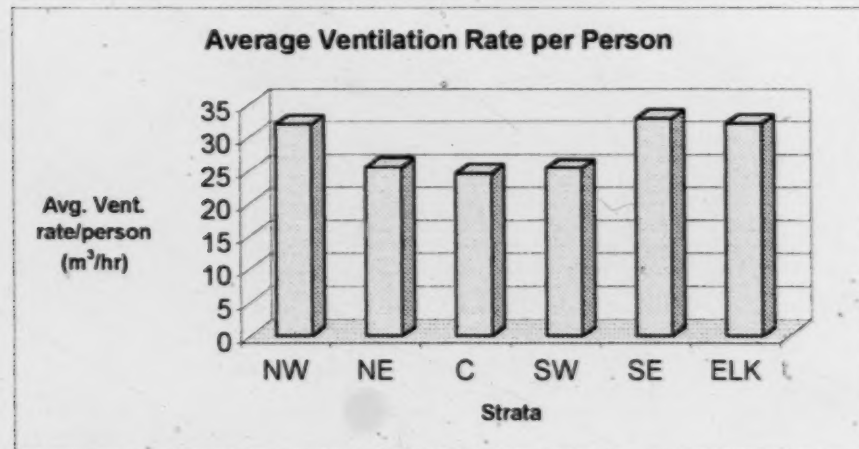
Table 9 Baseline Data of Individual Strata for 43 schools.

Strata Designation		Vent. Rate/ Person m ³ /hr	CO ₂ (mg/m ³)	CO (mg/m ³)	Temp. °C	Relative Humidity (%)
NW (n = 6)	Mean	31.9	1921	0.3	21	24
	Stand. Dev.	4.6	551	0.5	0.8	2.8
C (n = 5)	Mean	24.6	1638	0.1	22	24
	Stand. Dev.	13.3	398	0.3	0.8	6.9
SW (n = 6)	Mean	25.4	1712	0.5	22	24
	Stand. Dev.	2.9	360	0.1	1.3	5.8
SE (n = 8)	Mean	33.4	1672	0.3	21	25
	Stand. Dev.	12.4	477	0.5	1.6	5.8
NE (n = 7)	Mean	25.6	1987	0.7	21	23
	Stand. Dev.	3.8	419	0.3	0.8	5.5
ELK (n = 11)	Mean	32.2	1989	0.9	21	26
	Stand. Dev.	5.2	936	0.5	1.2	4.5

NW -North West SW -South West
 NE -North East SE -South East
 C -Central ELK -Elk Island District

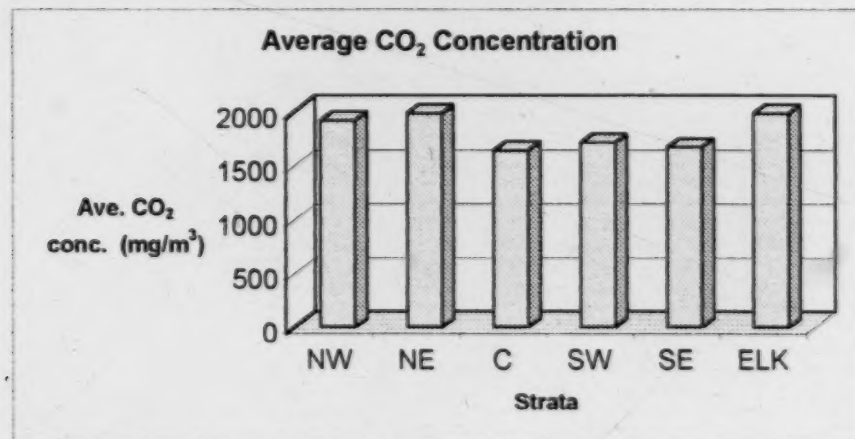
bar charts plots (Figure 17 to 21). These plots also enabled the observation of the relationship between parameters. The distributions of average ventilation rate per person in six strata are provided in Figure 17. Schools in the SE stratum appeared to have the highest ventilation rate or outdoor air supplied rate per person.

This was closely followed by ELK stratum while C stratum reported the lowest outdoor air supplied rate per student. The distribution of CO₂ levels (Figure 18) across six strata indicates that NW, NE and ELK strata were slightly above 1800 mg/m³ (1000 ppm). This suggests air short-circuiting in the space due to a high number of students close to sampling locations of non-sedentary activities.



NW	-North West	SW	-South West
NE	-North East	SE	-South East
C	-Central	ELK	-Elk Island District

Figure 17 Distribution of Average Ventilation Rate per Person in Six Strata.



NW	-North West	SW	-South West
NE	-North East	SE	-South East
C	-Central	ELK	-Elk Island District

Figure 18 Distribution of Average Indoor CO₂ Concentration in Six Strata.

Average CO concentrations were highest in NE and lowest in ELK (Figure 19). In Figure 20, the C stratum reported the highest temperature level. The distribution of relative humidity levels (Figure 21) indicated that ELK stratum had the highest relative humidity of 26%. NE stratum recorded the lowest relative humidity of 23%.

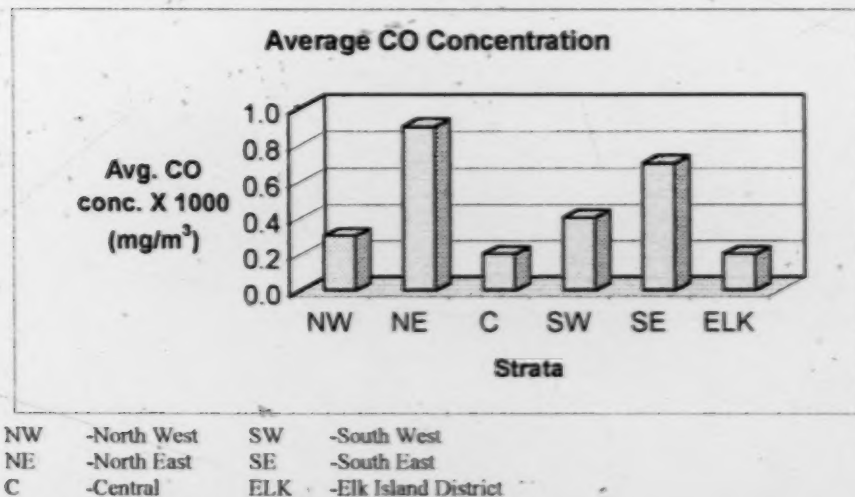


Figure 19 Distributions of Average Indoor CO Concentrations in Six Strata.

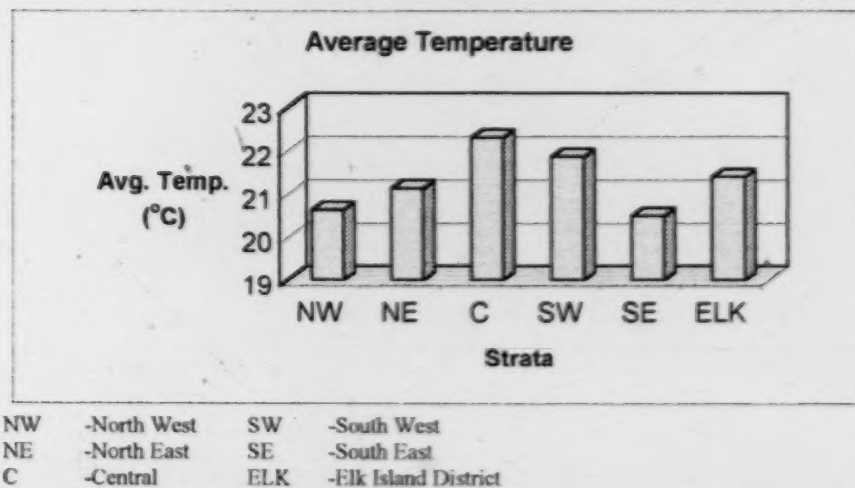


Figure 20 Distributions of Average Indoor Temperature Levels in Six Strata.

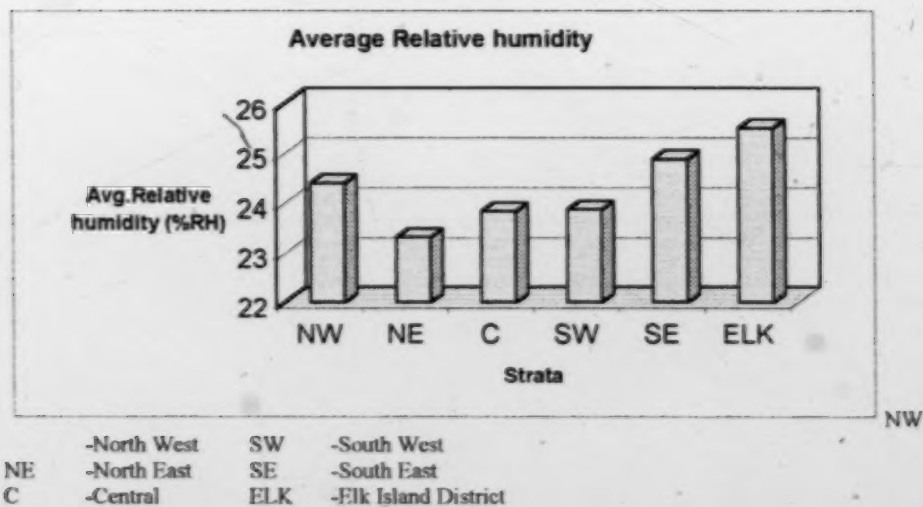


Figure 21 Distributions of Average Indoor Relative Humidity in Six Strata.

5.3.3 Comparison of Baseline Data with Standards

Mean baseline levels of parameters targeted by this study (based on geographical stratification) were reported for each stratum. These baseline levels (Table 10a) were compared with IAQ and comfort standards (Table 10b). Mean ventilation rates were comparable with ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality. CO₂ and CO concentrations were within the Canadian Exposure Guidelines for Residential Indoor Air Quality (Health Canada 2000). Average temperature and average relative humidity levels in each stratum were also comparable with ASHRAE Standard 55-1991, Thermal Environmental Conditions for Human Occupancy and ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality.

These inferences were made based on considerations that some differences exist between the methodology and criteria in which the field sampling were conducted. Some of these differences are as follows: First, ASHRAE standard 62 - 2000, is based

on 100% outdoor airflow rates while Canadian Exposure Guidelines for Residential Indoor Air Quality were based on epidemiological studies (Health Canada 2000). Second, due to energy conservation methods employed in the participating schools, field sampling was conducted in the atmosphere of less than 100% outdoor air supply. Whereas IAQ standards were established based on 100% outdoor air supply. Third, the sampling methodology and sampling periods used in the establishment of standards were different from those in which the results of this study were obtained. ASHRAE comfort standards were based on summer conditions, when buildings are cooled and winter conditions, when buildings are warmed in order to account for

Table 10a Baseline Data according to Geographical Regions

Strata Designation	Statistics	Vent. Rate/ Person m ³ /hr	CO ₂ (mg/m ³)	CO (mg/m ³)	Temp. °C	Relative Humidity (%)
NW (n = 6)	Mean	31.9	1921	0.3	21	24
	Stand. Dev.	4.6	551	0.5	0.8	2.8
C (n = 5)	Mean	24.6	1638	0.1	22	24
	Stand. Dev.	13.3	398	0.3	0.8	6.9
SW (n = 6)	Mean	25.4	1712	0.5	22	24
	Stand. Dev.	2.9	360	0.1	1.3	5.8
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	Stand. Dev.	12.4	477	0.5	1.6	5.8
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ELK (n = 11)	Mean	32.2	1989	0.9	21	26
	Stand. Dev.	5.2	936	0.5	1.2	4.5

NW -North West SW -South West
 NE -North East SE -South East
 C -Central ELK -Elk Island District

Table 10b IAQ and Comfort Standards.

Standards				
Vent. Rate/ Person m ³ /hr	CO ₂ (mg/m ³)	CO (mg/m ³)	Temp. °C	Relative Humidity (%)
25.5 to 34 ¹	≤ 6300 ²	≤ 29 ²	20 to 24 ³	30 ³

1 ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality

2 Canadian Exposure Guidelines for Residential Indoor Air Quality

3 ASHRAE Standard 55-1982, Thermal Environmental Conditions for Human Occupancy.

seasonal changes and clothing habits (Givoni 1991). In this study, the summer season was not represented in the field sampling. Fourth, ASHRAE comfort zone specifies boundaries of air temperature and humidity for sedentary people within which a mechanical system has to maintain the indoor climate. Activities in classrooms were not always sedentary.

5.3.4 Analysis of Highest and Lowest Values of Targeted Parameters

Visual inspection was a method used to analyze the baseline data reported for 43 schools. While average levels of parameters reported were comparable with both IAQ and comfort standards used in this study, the visual inspection of results obtained for 129 spaces from 43 schools indicated some discrepancies. Through visual inspection of the baseline data obtained for each parameter, the highest and lowest value of each parameter for 129 spaces was identified. In each space, of the 129 spaces (three spaces per school) comprising 43 schools, 15 minute samples were collected for CO, CO₂, temperature and relative humidity using the Q-track while the Velocicalc Plus Air Meter was used to measure outdoor air velocities supplied indoors from each diffuser and air grille present in each space. Airflow rates were calculated from air velocities using the continuity equation (Equation 5) and corrected by applying the linear regression model (Equation 8).

Through visual inspection, the highest and lowest values for ventilation rates, CO, CO₂, temperature and relative humidity are presented in Table 11. Table 11 indicates that between these two limits (highest and lowest levels), ventilation rate per person were below and above ASHRAE Standard 62-2000, Ventilation for Acceptable Indoor Air Quality (25.5 to 34m³/hr), respectively.

Table 11 Highest and Lowest Values for Parameters drawn from 129 Spaces.

Parameter	Lowest Values	Highest Values
Ventilation rates per Person (m ³ /hr)	18	60
CO ₂ (mg/m ³)	598	3645
CO (mg/m ³)	0	2.3
Temperature (°C)	16	25
Relative humidity (%RH)	14	37

The lowest and highest values reported for CO₂ and CO concentrations in 129 spaces were within the Canadian Exposure Guidelines for Residential Indoor Air Quality (6300 mg/m³ and 29 mg/m³ respectively). Temperature and relative humidity levels exhibited by the lowest and highest levels were under and above ASHRAE comfort standard (ASHRAE Standard 55 - 1982, Thermal Environmental Conditions for Human Occupancy). This standard specifies temperature levels to be between 20 and 24°C while relative humidity levels are specified as 30% RH to ensure occupant comfort.

Several reasons have been attributed for under and over predictions of ventilation rate per person, CO, CO₂, temperature and relative humidity in the indoor environment. Mostly, studies have cited occupant density at the time of sampling, air short-circuiting resulting from variable air volume (VAV) ventilation system or due to convective air currents, the operation of a combustion system indoors etc. (Desrocher

1986, Gagge et al. 1971, Croome and Roberts 1981, Apte and Traynor 1986). The reasons for the highest and lowest values obtained for each parameter measured in this study are as follows:

5.3.4.1 Ventilation Rate per Person

Several reasons have been documented for over and under prediction of ventilation rates. Ventilation rates per person depend on the number of occupants in individual spaces at the time of sampling (Giovoni 1991). Therefore, spaces with a smaller occupant density reported higher ventilation rates than spaces filled to their capacities. This is demonstrated by two extremes values for ventilation rates in spaces sampled. Examination of the room survey information for these spaces indicated occupancy rates of 8 persons for the space with the highest ventilation rate per person and 35 persons for the space with the lowest ventilation rate per person.

Another reason for under and over prediction of ventilation rates is air short-circuiting of variable air volume (VAV) mechanical ventilation systems. As previously mentioned, VAV systems have been known to return indoor air without completely mixing with the required portion of outdoor air before recirculation indoors (Hanson and Burroughs 1998). This could also contribute to the accumulation of other contaminants in enclosed spaces (Woods 1986).

Based on ASHRAE Standard 62-2000, Ventilation Rate Procedure for Acceptable Indoor Air Quality, indoor ventilation rates are affected by the number of spaces served by a particular ventilation system. In contrast to a unit ventilation system, ASHRAE Standard 62-1981, Ventilation for Acceptable Indoor Air Quality recommended that when multiple spaces are served by a central ventilation system the outdoor air supplied should be divided by all the spaces served. This was ignored in

this study due to the absence of comprehensive blueprints for schools investigated, which would have enabled field investigators to trace all air duct lines to their appropriate spaces.

5.3.4.2 Carbon Dioxide

The relationship between indoor carbon dioxide levels and the efficiency of ventilation systems has been well documented (Hanson and Burroughs 1998, Love 1985, Kuo et al. 1982). Indoor CO₂ levels are significantly reduced by ventilation air, therefore indoor CO₂ levels in spaces have been used to indicate the efficiency of the ventilation systems serving those spaces. However, high CO₂ concentrations could also be attributed to lack of ventilation effectiveness (i.e. the amount of air that actually reaches the occupants of a space). Therefore when all other factors relating to the indoor environment are eliminated, indoor CO₂ above 1800 mg/m³ (1000 ppm) may also refer to deficiencies in the ventilation system (Hanson and Burroughs 1998). For instance, the dampers may have been closed when they should be open in order to allow the intake of outdoor air into the ventilation system. The result is that a lower than the required amount of outdoor air required to dilute indoor CO₂ level to the acceptable levels for indoor occupant comfort is supplied.

The highest indoor CO₂ level reported (Table 11) suggests a higher than normal occupancy or lack of airflow resulting from either deficiency of the ventilation system in that space or air short-circuiting. Examination of the room survey information for this space indicated that the return air vent was located in the middle of two supply vents on the ceiling. This may have allowed most of the supply air to be returned without diluting with the room air. Air short-circuiting due to placement of supply/ return grills is implied for this space.

5.3.4.3 *Carbon Monoxide*

The concentration of carbon monoxide gas introduced directly into a space depends on the space design, ventilation system and combustion efficiency (Apte and Traynor 1986). The operation of furnace systems or gas heaters and burners in a space tend to increase the CO content in such spaces (Apte and Traynor 1986, Hines et al. 1993). The highest and lowest values of CO measured in this study were within acceptable limits however; the operations of combustion appliances are suggested in the space reporting the highest values of CO. The higher CO levels may also be attributed to automobiles if such spaces are close to parking lots.

5.3.4.4 *Temperature*

Several studies have established that a precise temperature in itself does not contribute to, or detract from, indoor air quality as long as the occupants are relatively comfortable (Gagge 1971, Croome and Sheratt 1977, Hanson and Burroughs 1998). Even though the ASHRAE comfort index established 20 - 24°C as the optimum temperature in which an occupant feels comfortable, the results of temperatures (Table 11) from individual spaces seem to demonstrate that thermal comfort is relative. This is because the highest and lowest temperatures recorded (16 and 25°C) indicated different thermal comfort levels of the occupants in the two spaces. The lowest temperature obtained (16°C) may also indicate the lack of uniform mixing resulting in temperature gradients in the location where the sampling instrument was placed.

5.3.4.5 Relative Humidity

Indoor relative humidity levels essentially reflect moisture content of outdoor air supplied and moisture content generated indoors. The highest and lowest levels of relative humidity levels in the total sample population seem to suggest the seasonal effects on the moisture content of outdoor air.

5.3.5 Distribution of Baseline Data

Normal probability plots was a method through which the baseline data of 43 schools were analyzed. Normal probability plots were carried out in order to establish the distribution of CO, CO₂, temperature, relative humidity and ventilation rates. The normal probability plots (Figure 22a to 22e) for CO₂, temperature and relative humidity indicate a normal distribution. In contrast, CO data indicate that some data were below detection point.

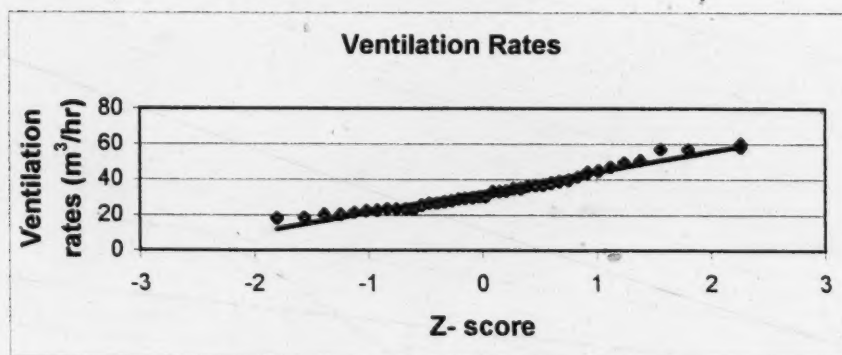


Figure 22a Normal Probability Plot for Ventilation Rates in 43 Schools.

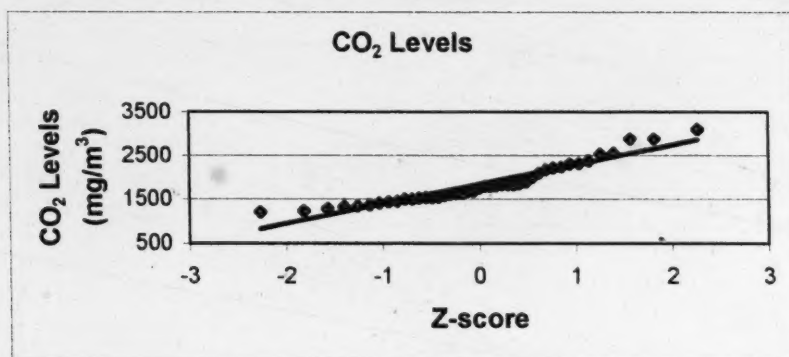


Figure 22b Normal Probability Plot for CO₂ Concentrations in 43 Schools.

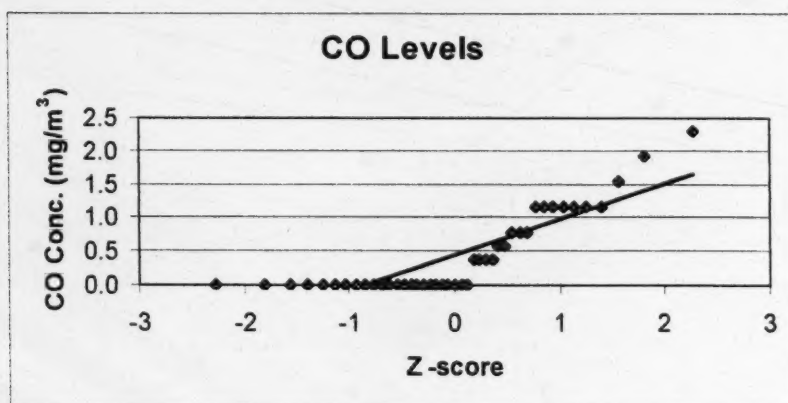


Figure 22c Normal Probability Plot for CO Concentrations in 43 Schools.

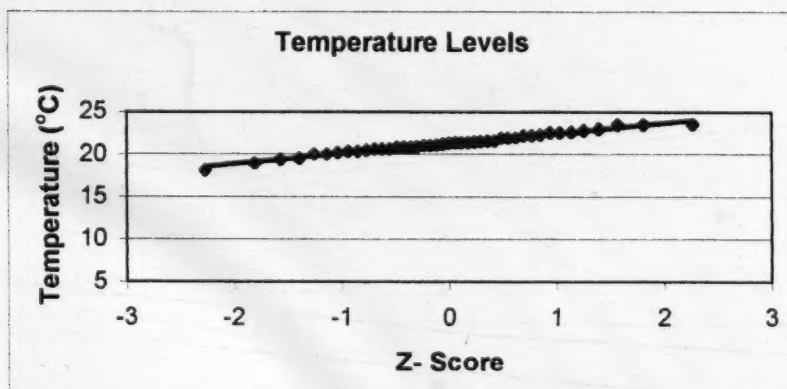


Figure 22d Normal Probability Plot for Temperature Levels in 43 Schools.

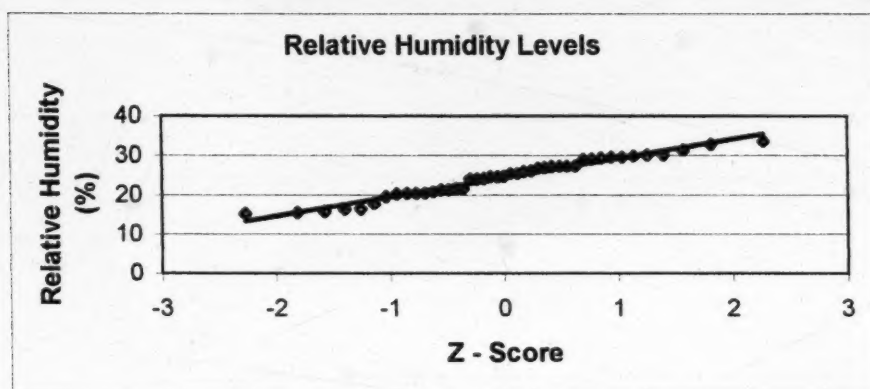


Figure 22e Normal Probability plot for Relative Humidity Levels in 43 Schools.

5.4 Analyses of Subset Data

Subset sample populations were generated in order to critically analyze factors that may influence indoor air quality. Specific to this study, the following subset data were analyzed:

"Within Space Variability" was analyzed in order to establish the CO₂ spatial variability within 12 randomly selected spaces. Three locations (Front, Center and Back) were identified in each of the 12 randomly selected spaces and the variability in CO₂ concentrations from these three locations in each space for twelve randomly spaces were examined. Variability in CO concentrations, relative humidity and temperatures within the aforementioned locations were ignored.

CO₂ Decay was another subset data examined by this study. CO₂ depletion in an empty but ventilated classroom was observed for three (3) hours in four randomly selected spaces.

Air exchange rate subset data were also examined. This subset enabled the comparison of air exchange rates obtained from two methods (CO₂ decay method and direct airflow measurements).

5.4.1 *Variability in CO₂ Concentrations Within Spaces*

It is widely assumed that air in an occupied space is uniformly mixed however the occurrence of short-circuiting of air in spaces may indicate otherwise. Air short-circuiting in spaces results in stagnant air zones in regions where air is not uniformly mixed resulting in the variability of CO₂ concentration in spaces. The indoor CO₂ concentration in a space is increased from its initial level based on the occupancy, efficiency of the ventilation system in operation and ventilation effectiveness. The number of occupant and CO₂ content of a space has a proportional relationship. Due to a deficiency in a ventilation system serving a space, an insufficient amount of outdoor air may be supplied to a space leading to a higher than specified CO₂ content in that space. Due to ventilation effectiveness less than 1 as a result of air short-circuiting, the desirable amount of air required for IAQ and occupant comfort may not be reaching all the occupants in that space. The results of "Within Space Variability" (Table 12 and 13) indicate the effect of occupancy and ventilation effectiveness on indoor CO₂ concentrations from twelve spaces. These spaces are summarized in two categories (A and B) possessing different characteristics.

Category "A" spaces had either or all of the following characteristics: open door at the back of the classroom, concentration of students at the front of the classroom and both supply and return air vents at the back of the classroom. Spaces in this category reported a lower CO₂ concentration at the back than in the front of the space.

The variability of CO₂ concentrations between the Back and Front locations in five spaces comprising Category "A" was analyzed through statistical hypothesis testing. A paired t-test ($\alpha = 5\%$) was performed to determine if significant differences existed between CO₂ concentrations at the Front and Back locations of five spaces.

Table 12 Category "A" spaces indicating lower CO₂ levels at the back of classrooms relative to the front at the time of sampling.

School Code	Space No.	CO ₂ Conc. (mg/m ³) and position of Q-track at the time of sampling	
		Back	Front
R1-C-015	4	1346	1492
R1-C-015	12	1040	1462
R1-NW-018	14	1379	1868
R1-C-022	205	1674	1863
R1-E-010	205	2468	2468

The results of the paired t-test indicate no significant difference ($t \text{ stat} < t$ critical) between the Back and Front locations (Appendix 24). A lack of significant differences is suggestive of predominantly outdoor sources such as increased air velocities due to open windows at the back of the classrooms. This could account for lower CO₂ concentrations at the back of the classrooms as a result of higher ventilation rates from natural ventilation.

In contrast to Category "A" spaces, Category "B" spaces (Table 13) had either or all of the following characteristics: closed door at the back of the classroom, concentration of students at the back of the classroom and both supply and return air vents at the front of the classroom.

Table 13 Category "B" indicating higher CO₂ concentrations (mg/m³) at the back of classrooms relative to the front.

School Code	Space No.	CO ₂ Conc. (mg/m ³) and position of Q-track at the time of Sampling	
		Back	Front
R1-C-015	13	1489	1292
R1-NE-008	8	1809	1438
R1-NE-008	6	1717	1582
R1-NE-008	2	1895	1620
R1-NW-018	11	1719	1649
R1-NW-018	7	1260	1076
R1-C-022	101	2842	1894

A paired t-test ($\alpha = 5\%$) was performed to determine if significant differences exist between CO₂ concentrations at the Back and Front locations for seven Category "B" spaces. The results of the test presented in Appendix 24 indicate significant differences in CO₂ concentrations between the back and Front locations in Category "B" ($t_{stat} > t_{critical}$). This suggests indoor sources such as high level of occupancy or ventilation effectiveness less than one as the contributors to the variability of CO₂ in the spaces in Category "B".

5.4.2 CO₂ Decay Analysis

The trend in CO₂ depletion of an empty but ventilated classroom was observed from a CO₂ decay curve. CO₂ decay was measured for three hours after the students had left the selected spaces at the end of the school day. Chang and Lee (1998) reported that CO₂ depletion follows an exponential curve when the trend of the decay curve in an empty but ventilated space was observed.

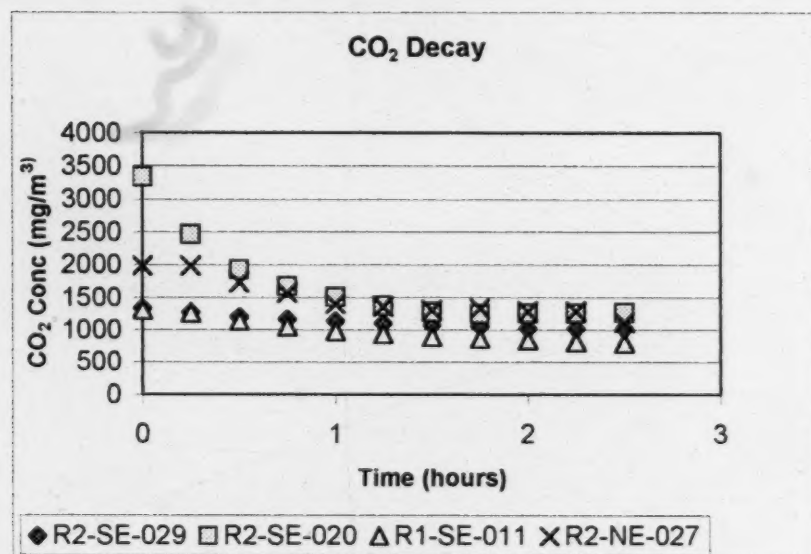


Figure 23 CO₂ Decay Curve

The decay curve (Figure 23) demonstrates this in the four spaces sampled. Spaces R2-SE-020 and R2-NE-027 show a steeper curvature suggesting higher ventilation rates or air exchange rates than spaces R2-SE-029 and R1-SE-011 (Persily 1988).

5.4.3 Comparison of Air Exchange Rates

Air exchange rate refers to the number of air changes per unit time within a space volume. Air exchange rates have been used, as another method of reporting the ventilation rates required ensuring acceptable indoor air quality and indoor occupant comfort of spaces. Air change rates takes into consideration the volume of the enclosure, which may impact on the rate of air mixing. Subset data were collected to allow the comparison of the air exchange rates obtained through both the CO₂ decay method and air exchange rates obtained through direct airflow measurement from four randomly selected classrooms.

5.4.3 Comparison of Air Exchange Rates

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The CO₂ decay method of obtaining air exchange rates was established by American Society of Testing and Materials (ASTM) and employed by several studies (Ryan and Lambert 1991, Persily 1988, Yocom et al. 1974). In the four randomly selected classrooms, CO₂ was sampled for 3 hours at the end of a school day after the students had left the class. It was mandatory that the ventilation rate throughout the day was not altered and all natural ventilation sources such as windows and doors were closed. Using the decay equation and a methodology detailed in Appendix 25, the air exchange rates were obtained for these four spaces.

In the direct air measurement method, the Velocicalc Plus Air Velocity Meter was used to take air velocities measurements in the same classrooms. The air velocities were subsequently converted to airflow rates by the continuity equation (Equation 5). Calculated airflow rates were also corrected through the application of the linear model (Equation 8). Dividing the airflow rates of each of the four spaces by their respective space volume, the air exchange rates were obtained from direct air measurements. The air exchange rates obtained for both the CO₂ decay and direct air measurement methods are presented in Table 14. Ventilation rates are also presented in Table 14. These were obtained from direct air velocity measurements using the Velocicalc Plus Air Velocity Meter.

Several studies have reported air exchange rates in the range of 0.5 to 1 per hour for spaces with closed windows (Ryan and Lambert 1991, Persily 1988, Yocom et al. 1974). Dols and Persily 1993 also reported that during normal occupancy with frequent opening of external doors, air exchange rate could be in the range of 3 to 3.5 per hour. The air exchange rates (Table 14) from the CO₂ decay method were much lower than those reported by other studies mentioned above. The discrepancies observed between air exchange rates obtained in this study and those reported by

other studies may be attributed to the fact that the ventilation rates used in this study are much lower than the ventilation rates used to calculate air exchange rates in the aforementioned studies.

Table 14 Comparison of Air Exchange Rates from CO₂ Decay Method and Direct Air Velocity Measurements.

School Codes	Air Exchange Rates (space volumes per hour)		Ventilation Rates (m ³ /hr)
	CO ₂ Decay Method	Direct Flow rate Measurement	
R2-SE-029	0.1	0.1	1133
R2-SE-020	0.4	0.1	447
R1-SE-011	0.2	0.3	2141
R2-NE-027	0.2	0.1	450

5.5 Quality Assurance and Quality Control

Environmental field studies are constrained by several external and internal environmental factors, which may introduce bias into results obtained. Consequently, quality control methods and procedures were established to ensure precision of reported results. Quality assurance seeks to evaluate conformance to set procedures and standards (Smith 1986).

Quality control methods utilized included procedures and protocols. Sampling protocols were established in order to ensure consistency in locations where air instruments were placed during sampling. This reduced bias that may have been introduced from three field investigators handling the same instruments at different times.

Variation in sizes of spaces and sitting arrangements made it impossible to always adhere to precise sampling locations stipulated by the sampling protocol. Also,

"EPSB blueprint for learning" meant that classrooms were not interrupted before 10 : 30 am. Several additions were thus incorporated to fine-tune the sampling protocol. A pilot study was also instrumental in ensuring quality control of the protocol and procedures before actual field sampling commenced. Other protocols established to ensure efficiency of field investigations were conduct protocol and IAQ advisory used in reporting data to appropriate authorities.

Sampling instruments were calibrated before the beginning of each sampling round as directed by the sampling protocol to ensure results were within manufacturer's precision of $\pm 3\%$. Correction of airflow rates from the Velocicalc Plus Air velocity Meter was achieved by the derivation of a linear model with a standard deviation of ± 0.95 .

Statistical methods were also used as quality improvement methods. Random sampling was used in all space selection processes. Two-level stratification was incorporated into the experimental design because studies indicated this increased the level of precision of parameters evaluated and results reported (Prasad and Rao 1969).

Communication was also a tool for ensuring quality assurance. Several meetings held with the project steering committee provided a forum for discussion and ensured that objectives of individual school boards were met. Each meeting saw the fine-tuning of procedures, questionnaires and protocols used in this study. Effective communication thus established between project sponsor and field investigators enabled customer satisfaction to be achieved.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

The overall objective of this study was to determine baseline levels for ventilation rates, carbon dioxide, carbon monoxide, temperature and relative humidity levels in public schools. The results provided in Table 9 presented baseline levels according to six geographical regions identified as North West, North East, Central, South West, South East and Elk Island District. The distributions of each parameter across six strata were also reported through the use of barcharts (Figure 17 to 21).

Outdoor samples were used as controls. The results of paired t - test ($\alpha = 5\%$) confirmed no significant differences between indoor and outdoor levels for CO and relative humidity levels thereby suggesting outdoor sources as predominant contributors to indoor levels of parameters investigated. In contrast, the result of paired t - test ($\alpha = 5\%$) indicated significant differences between indoor and outdoor levels of CO₂ and temperature levels. These indicate indoor sources as predominant contributors to indoor CO₂ and temperature levels.

Another objective specific to this study was to describe experimental design procedures. This was accomplished in Section 3.4 indicating two-level stratification with random sampling design. The first level being geographical stratification while the second stratification level was water damage/no water damage. While the first level stratification was used as the basis for the analyses of the baseline result, the second level stratification was ignored in the analyses of results because very small and highly variable sample sizes were obtained from this second level stratification. Random sampling was employed in all sample selections processes.

Another objective specific to this study was to describe IAQ parameters and comfort factors. This was accomplished in Section 2.3 with the description of carbon dioxide and carbon monoxide as indicators of indoor air quality. The description of comfort factors was achieved in Section 2.7 with the description of temperature, relative humidity and ventilation as comfort factors.

The baseline levels reported for these studies were consistent with both IAQ and comfort standards. Ventilation rates data reported some discrepancies; reported ventilation rates were below and above ASHRAE's recommended rates. These were attributed to lack of uniform mixing in spaces rather than inadequate ventilation rates.

From the analysis of the within space subset, it was determined that two sets of conditions existed in the classrooms sampled. Categories A and B spaces (Table 12 and 13) established that if ventilation was not effective, it could result in lack of uniform mixing in some locations within spaces and higher CO₂ concentrations in those locations. Through statistical hypothesis testing, it was determined that low indoor CO₂ concentration may be attributed to increased air velocities from natural ventilation sources while high indoor CO₂ concentration may be attributed to indoor sources such as increased occupancy or low ventilation effectiveness.

Air exchange rates obtained from CO₂ decay method and from direct measurements of air velocities show comparable results. Air exchange rates per hour were however low when compared against published results of Dols and Persily 1993.

The objectives for this study were achieved, however several improvements could be made if a similar study was attempted. The main consideration is to either reduce the sample size or choose a sample size possessing the same characteristics in terms of class design and classroom schedules. This is because variations in class sizes and activity pattern meant that the results were not compared on the same basis.

The second level stratification could be improved by increasing the sample sizes without water damage while reducing the number of samples with water damage in each stratum. This could be achieved by ensuring that during random sampling, the required number of samples with and without water damage is specified.

Another consideration is natural ventilation. This was observed to contribute to the amount of air supplied to classrooms; therefore in future the effect of natural ventilation on indoor levels of both IAQ and comfort parameters should be investigated more thoroughly.

Finally, the sampling duration for spot samples should be increased from 15 minutes to at least one hour so that it can be comparable to the Canadian Exposure Guidelines for Residential Indoor Air Quality (i.e. acceptable short term exposure range) (Health Canada 2000).

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HEALTH RESEARCH ETHICS BOARD

REQUEST FOR ETHICS REVIEW FORM

***Note - Please complete this form by following the "Instructions for Completing the**

SECTION A: GENERAL INFORMATION

A1. Project Title
Title of Project: <i>Indoor Air Quality in Edmonton Public and Elk Island Public and Catholic Schools</i>

A2. Applicant Information
Name: Mary Unobe, Corinne Stocco, Lorelei Betke Title: Graduate Students Department: Environmental Engineering. Mailing Address: #304, Environmental Building, University of Alberta City & Province:

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A3. Co-Applicant Information			
Name: Dr Warren Kindzierski Title: Assistant Professor Department: Environmental Engineering. Mailing Address: #304, Environmental Building, University of Alberta			
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E-mail Address: warri.kinzierski@ualberta.ca

A3. Co-Applicant Information			
Name: Steven Probert Title: Air Quality Specialist Department: Community Care and Public health, Capital Health Authority Mailing Address: Suite 300, 10216 -124 Street			
City & Province	Postal code	Phone	Fax
Edmonton, Alberta	T5N 4A3	413-7933	482 - 5383

A4. Indication of Department Support for the Implementation of the Project.	
Name of Dept. Chair, Assoc. dean of Research, or Supervisor:	
Dr. Terry Hrudey	
Title: Professor and Chair of Civil and Environmental Engineering	
Signature	Date:

A5. Co-Investigators/Thesis Committee

Is this project for a graduate thesis? (V) Yes () No

If yes, please provide the names, departments, and phone numbers of your thesis committee.

Name	Department/Program	Phone
Warren Kindzierski	Environmental Engineering	492-0247
Selma Guigard	Environmental Engineering	492-8585
Jerry Leonard	Agricultural Food and Nutritional Science	492-0107

6. Expedited Review

If the Study procedures are LIMITED to any of the following, please check ()

☐	Analysis of blood, urine or any other biological specimen already collected.
☐	Examination of patient, medical, or institutional records.
☐	Modification of a previously approved protocol (specify title and approval data):
☐	Secondary analysis of data.
☐	Use of biological specimens normally discarded.

A7. Type of InvestigationWhich one of the following best describes the type of investigation proposed?
Check (V) more than one if appropriate.

☐	Clinical Trial	☐	Multi-centre Trial
☐	Drug Study	☐	Pilot Study
☐	Epidemiological Study	☐	Qualitative Study
☐	First Application in Humans	☐	Technology Assessment / Development
☐	Sequel to Previously Approved Project (specify title and approval date):		

V	Other (specify): This study involves collection of information through field questionnaires, and collection of air quality data through a direct method of field sampling and laboratory analysis by the National Center for Mycology.
---	--

A8. Site of Research	
Where will the research be conducted? Check (✓) more than one if appropriate. Specify the area/department/program.	
Alberta Cancer Board Sites:	
☐	Cross Cancer Institute:
Capital Health Authority Sites:	
☐	Community Care and Public Health:
☐	Glenrose Rehabilitation Hospital:
☐	North Edmonton Community Health Centre:
☐	Royal Alexandra Hospital:
☐	Stollery Children's Health Centre:
☐	Sturgeon Community Hospital and Health Centre:
☐	University of Alberta Hospital:
Caritas Health Group Sites:	
☐	Edmonton General Hospital:
☐	Grey Nuns Community Hospital and Health Centre:
☐	Misericordia Community Hospital and Health Centre:
University of Alberta Sites:	
☐	Specify (e.g. Corbett Clinic):
Other:	
✓	Specify: Schools within Capital Health Region and under the jurisdiction of Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.
Letters of Support:	
☐ Pending	☒ Attached ☐ Not Applicable

A9. Funding / Budget	
How is the project funded? Please check (✓) the appropriate box.	
✓	Funding approved; specify source(s): Edmonton Community Lottery Board and Strathcona Community Lottery Board
☐	Funding pending; specify source(s):
☐	No external funding required.
Budget	
✓	Please check here (✓) that you have attached a budget summary. The summary must include details of investigator payments and recruitment incentives (if present). Please attach the budget as an appendix to the form.

A10. Remuneration	
<i>Are any of the investigators involved receiving any direct personal remuneration or other personal or family financial benefits (either direct or indirect) for taking part in this investigation?</i>	
☒	Yes. If so, append a letter detailing these activities. Please attach this letter to your budget summary.
☐	No.

A11. Safety Approvals					
<i>Please check (✓) whether or not this study requires any of the following safety approvals. If a safety approval is needed, please indicate whether the approval documentation is pending or attached as an appendix to this form.</i>					
Biohazardous Materials:					
☒	Not Applicable	☐	Pending	☐	Attached
Electromechanical:					
☒	Not Applicable	☐	Pending	☐	Attached
Health Protection Branch or Other Canadian Federal Agency:					
☒	Not Applicable	☐	Pending	☐	Attached
Radiation:					
☒	Not Applicable	☐	Pending	☐	Attached

SECTION B: DETAILS OF PROJECT

Description of Project

B 1. Provide a clear statement of the purpose and objectives of the project.

Capital Health Authority, Edmonton Public Schools, Elk Island Public and Elk Island Catholic Schools are in partnership with the University of Alberta to investigate fungal contamination in schools in the Capital Health Region. Although it is not believed that there is an air quality crisis in the schools, the purpose of this two-year study is to determine the status of mould in schools so that responsible authorities may develop an appropriate plan to ensure high indoor air quality (IAQ).

The investigation of indoor air quality in schools (with an emphasis on fungal contaminants) within the Capital Health Region arose for several reasons. First, other provinces and states such as Ontario and California have had major mould problems in their schools in the past. Second, Health Canada's Environment Health Directorate recommended that Canadian research initiatives be implemented to establish baseline levels of fungal contamination within public buildings (Env. Health Directorate, 1995). And third, within the past year, two Edmonton schools have had air quality issues, some of which were attributed to mould. Holyrood elementary school had a mould problem due to a water main break, resulting in musty odours, reported headaches and minor respiratory problems. Due to a combination of factors, including the presence of mould, occupants at Green view elementary school also complained of symptoms related to inhalation of fungal spores. It is important to determine whether or not these incidences were isolated mould problems, or if some Edmonton schools have poor IAQ and are in need of immediate remediation.

Many studies have already investigated fungal contaminants in schools across North America and Europe, however a study of this genre has not yet been undertaken in the Edmonton area. Since it is impossible to generalize the results of fungal contaminant studies over geoclimatic regions, a study in the mostly cool and dry Edmonton area (which would support a different fungi population) is required. There are four main research objectives in this study to determine presence of fungal contaminants in schools:

- . Develop local procedures and protocols for identifying, evaluating, and managing fungal contaminants in schools.
- . Identify parameters and conditions that contribute to fungal growth in schools.
- . Determine baseline levels and types of school fungal contaminants as well as associated indoor air quality parameters.
- . Develop cost effective fungal prevention and remediation strategies.

B2. State the hypotheses and/or research questions.

Do Edmonton Public schools and Elk Island Public & Catholic schools have indoor air quality problems?

Do fungal contaminants exist in the Capital Health Region schools? . If so, what conditions facilitate mould growth?

B3. Briefly summarize past human and/or animal research that has lead to this project.

Background

There are approximately 10,000 known species of fungi, and 2,000 new species are identified each year (Miller, 1992). Fungi's quick and asexual reproduction cycle results in the formation of an enormous quantity of spores (Gravesen, 1979). Fungi are heterotrophic and their food demands range over a broad spectrum of organic materials (Gravesen, 1979). In the context of this research, fungi are mainly mesophilic with an optimal temperature for growth between 20-

40°C, and prefer more acidic conditions around pH 5-6 (Gravesen, 1979). Most spores in indoor air originate from the outdoors, (Pasanen, 1992) and readily enter by circulating through doorways, windows, and heating, ventilation and air-conditioning (HV AC) systems (American Academy of Pediatrics, 1998). Fungus can grow on virtually any substrate including: glass, paint, rubber, textiles, electrical equipment, and organic material such as paper, cardboard, ceiling tiles and wood products (Miller, 1992). There are three main factors that contribute to their growth: sufficient water, mild temperatures, and organic nutrient.

Adverse health effects

Between 6-15% of the Canadian population is allergic to fungi (Miller, 1992). Whether or not people exposed to fungi develop symptoms depends on the nature of the fungal material, the amount of exposure, and the susceptibility of exposed persons (NY Dept of Health, 2000). Susceptibility varies with genetic predisposition, age, and state of health (NY Dept of Health, 2000). Fungi are frequently implicated in environments with poor indoor air quality and are associated with increased fatigue, concentration difficulties, headaches, eye, skin and throat irritation, increased frequency of common colds, wheeze and skin sensitization (Whillans, 1995). Risk of flu symptoms; diarrhea, dermatitis, malaise, epistaxia, hypersensitivity pneumonitis, and fever also increases in those exposed to mould (Health Canada, 1995). Fungal infections may also occur in the immunosuppressed (Miller, 1992).

Indoor Air Quality Guidelines:

Numerous authors maintain that a tolerable exposure to mould spores in indoor air ranges from 100-1000 CFU/m³ (colon forming units). National Health & Welfare Canada suggests that up to 150 CFU/m in government office buildings is acceptable if there is a mixture of species reflective of the outdoor air spores. And in the summer time, 500 CFU/m³ is acceptable if the species present are primarily tree and leaf fungi (Health Canada, 1995). Currently in Canada, no limits or standards for indoor air quality in schools exists.

Literature

Literature states that schools are likely to develop air quality problems due to:

- . Building age;
- . Type of HV AC system;
- . Poor maintenance of schools & those with water leakage problems.

Description of Sample/Population

B4. Describe the numbers and type(s) of subjects to be included. If appropriate, specify the number of subjects in each study group. Provide a rationale for the sample size and include sample size calculations where appropriate.

There are a total of 261 schools within the Capital Health Region that are included in this investigation. There will be approximately 40 schools that will be participating which will have been picked by using stratification and random sampling techniques to allow for parametric statistical analysis. The number of schools sampled is limited by budgetary and time constraints.

Stratification of schools into three levels:

- . Geographic location: EPSB versus other
- . Age of students: elementary schools versus others
- . Utilization rate: low versus high (will be able to incorporate actual ranges)

Within each randomly selected school, four samples will be taken in different locations (eg. classrooms, library, bathrooms), and 15% of the samples will be performed in duplicate.

B5. List any subject inclusion/exclusion criteria.

Not Applicable. All schools within the Capital Health Region have an equal chance of being randomly selected for the study.

B6. Please check (✓) if any of the subjects who will be recruited fall into one or more of the following categories:

☐	Under 18 years of age
☐	Cognitively Impaired
☐	Residing in institutions (e.g. prison, extended care facility)
☐	Students
☐	Employees of researchers' organization
☐	Have language barriers (e.g. illiterate, not English-speaking, dysphasic)
☐	In another country

Description of Research Procedures

B7. Provide a summary of the design and procedures of the research. Provide details on the methods of data collection and data analysis, time commitment for the subjects etc. Please note that any and all study measures need to be appended to the copies of the research / grant proposal (e.g. questionnaire, interview guides, rating scales etc.).

Data Collection:

Questionnaires as well as visual inspection will be used to obtain information regarding the school maintenance history, central HVAC system and the room to be sampled (see attachment #10, 11, 12).

1. Pre-Screening Survey

- General characterization of schools
- Currently being used for experimental design purposes
- Completed by school facilities personnel
- Estimated completion time of one hour

2. Screening Survey

- Provides information regarding the different phases with respect to construction type, water damage, building materials etc. This will enable the subsequent selection of rooms to be sampled.
- The questionnaire is self applied and will be completed by the school facility personnel.
- Estimated completion time of half an hour.

3. School Maintenance History Survey

- Determine episodes of water damage and recent renovations/upgrades in the school. Maintenance of school mechanical systems will also be assessed and general health of the school population evaluated.
- Self-applied
- Completed by school facility personnel
- Estimated completion time of one hour, pilot test pending

4. Central HVAC Survey

- Assesses the general condition of the central HVAC
- Inspection and interview
- Completed by field investigator with the assistance of a facility personnel and the school custodian.
- One completed for each central HVAC system
- Estimated completion time of one hour, pilot test pending

5. Room survey

- Investigate the indoor air quality of individual rooms.
- Self-applied
- Completed by a field investigator
- Estimated completion time of one hour, pilot test pending

School selection:

- Experimental design will be based on a stratified sampling approach. For a summary of statistical design, please refer to B4.

Data Analysis:

- Parametric statistical analysis
- Correlate measured results (CO, CO₂, temperature, humidity, fungal count) and survey data

Procedure of Research:

Awareness campaign (pretest):

- There will be a press release one day prior to the sampling date informing the public of the study, the participating parties and a brief description of the activity that will ensue.
- Information sheet will be forwarded to parents in September and reminders will be issued for subsequent sampling rounds.

- Introductory letter and information sheet to the principal of the selected schools will be faxed by August 31, 2001. This will be followed up by a phone call to further discuss the letter and where necessary a meeting between the field investigators and the principal can be arranged to further clarify any issues. The commitment and assistance of the principal will be subsequently sought and obtained. Up to ten principals may choose not to participate without compromising the integrity of the experimental design.

Field procedures will be divided into round one (September/October), round two (December/January) and round three (February/March 2002). The activities of round two and three will be a repetition of round one in the different selected schools.

Procedures of each round:

- Upon receipt of response forms an appointment is made with participating schools. Confirmation of appointment is made by telephone one day before the sampling date.
- Field investigators arrive in selected school at prescheduled time and meet with the school contact, facilities services contact and head custodian.
- A field investigator with assistance of facilities personnel and the head custodian will complete HVAC survey.
- Sampling location is confirmed from schematic and samplers are deployed to the location inside and outside as per sampling protocol (see attachment #13)
- The visit is completed in half a day with one hour spent in inspection with the assistance of the facility personnel and a sampling period of about 20 minutes in each room.
- Samples are transported to the Provincial Public Health Laboratory for analysis.

Air sampling and analysis equipment:

The following air samplers will be used for both indoor and outdoor sampling (please see attachment #13)

- RCS plus handheld sampler with Rose Bengal Agar will be used for mould sampling.
- Q-track will be used for the measurement of CO, CO₂, temperature and relative humidity
- Velocical plus air velocity meter will be used for measurement of air flowrate

Laboratory analysis:

- Incubate sample for 7 days at 28-30°C
- Identify mould species using microscopic mount and count the mould colonies observed.

Questionnaires (attachment numbers 8, 9, 10, 11, 12):

Prescreening, Screening, School Maintenance History, HVAC, and Room Surveys

B8. Which treatments or procedures are additional to those required for standard patient care?

Not Applicable.

B9. If the procedures include a blind, under what conditions will the code be broken and what provisions have been made for this? Who will have the code?

Not Applicable.

Obtaining Consent

B10. Clearly detail who will be recruiting subjects and obtaining consent, and the procedures for doing this. If appropriate specify whether subjects will be randomly assigned to groups before or after consent has been attained.

On behalf of Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools, school superintendents have agreed to participate in this study (see attachment #15). Facilities services personnel will be asked to complete a consent form before participating in onsite HVAC investigations (see attachment #6). In addition, school principals will be asked to complete a consent form on behalf of their schools (see attachment #4). Consent forms will be mailed to schools three weeks prior to scheduled sampling times. Schools will be randomly assigned to groups before consent has been obtained from facilities personnel and principals.

B11. Specify methods for dealing with groups identified in #B6. If the subjects are not able/competent to give fully informed consent, who will consent on their behalf?

Not Applicable.

B12. If the subjects will be offered compensation for participating in the research, provide details. Specify the amount, what the compensation is for, and how payment will be determined for subjects who do not complete the study.

Not Applicable.

B13. Do any of the procedures include the use of deception or partial disclosure of information to subjects?

No.

If yes, provide rationale for the deception or partial disclosure. Describe the procedures for (a) debriefing the subjects and (b) giving them a second opportunity to consent to participate after debriefing.

Not Applicable.

Recruitment Aids/Information Letters/Consent Forms

B14. Are you planning to use any recruitment aids such as posters, newspaper advertisements, radio announcements, or letters of invitation?

Yes, information letters.

If so, please indicate the reading level of each aid and check (✓) if it has been attached to the form as an appendix.

Recruitment Aid #1 – Specify (e.g. poster, letter etc.):

✓	Not Applicable		Reading Level		Attached
---	----------------	--	---------------	--	----------

Recruitment Aid #2 – Specify:

✓	Not Applicable		Reading Level		Attached
---	----------------	--	---------------	--	----------

Information Letter #1 – Information letter to principle.

	Not Applicable	12.0	Reading Level	✓	Attached
--	----------------	------	---------------	---	----------

Information Letter #2 – Information sheet for parents.

	Not Applicable	9.2	Reading Level	✓	Attached
--	----------------	-----	---------------	---	----------

Consent Form #1 – Consent form for school principals

	Not Applicable	12.0	Reading Level	✓	Attached
--	----------------	------	---------------	---	----------

Consent Form #2 – Consent form for facilities services personnel

	Not Applicable	11.4	Reading Level	✓	Attached
--	----------------	------	---------------	---	----------

B15. What steps have been taken to make the recruitment aids, information letters, and consent forms comprehensible to the person(s) giving consent?

Information documents were reviewed by investigators, and the Steering Committee (including representatives of Capital Health Authority, Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools). Grade levels were determined using Word v7.0 Grammar check.

Risks and Benefits

B16. What are the benefits of the proposed research for the subject and/or for scientific knowledge in general?

The Capital Health Authority believes that this project will allow for enhancement of the local community's quality of life through better health for school children. Some of the community benefits include:

- Reducing the number of sick days, thereby decreasing the financial burden on the healthcare and education systems;
- Healthier children and teachers
- Proactive school IAQ management
- Improved public awareness about IAQ
- Status of IAQ within individual schools, and overall in Capital Health Region

B17. What adverse effects may result from the research? How will adverse effects be dealt with? Please note that adverse effects are not limited to physical risks, but include psychological, emotional, and spiritual risks as well.

There are no anticipated health or safety risks.

Privacy and Confidentiality

B18. What steps will be taken to respect the privacy of the subjects and protect confidential data?

This study will not call for personal information from students or staff. Information provided will be kept for at least five years in a secure area. All information will be held private, except when professional codes of ethics or legislation requires reporting.

B19. Identify any agencies or individuals who will have access to confidential data now or in the future.

Individuals: investigators, thesis committee

Agencies: Capital Health, Edmonton Public School Board, Elk Island School Board, Elk Island Catholic School District

B20. Do you anticipate any secondary analysis of the data? Please note that any secondary analysis requires further research ethics approval.

Yes. A research proposal by a University of Calgary graduate student is being considered for funding by the Capital Health Authority. The student would investigate possible correlations between indoor mould contamination and health concerns. As part of this study, the student might wish to do secondary analysis of data obtained in the IAQ study. An additional ethics approval would be sought prior to proceeding with this secondary analysis.

Health Research Ethics Board**biomedical research****health research**

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July 18, 2001

Ms. Lorelei Betke, Ms. Corinne Stocco, & Ms. Mary Unobe
304 Environmental Engineering Building
Department of Environmental Engineering

Dear Ms. Betke, Ms. Stocco, & Ms. Mary Unobe,

Re: Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.

Thank you for presenting the above study to the Health Research Ethics Board (B: Health Research) at the meeting of July 6, 2001. The board members appreciated the opportunity to learn of the research you are planning to conduct and to provide comments.

The board discussed the nature of your project following the meeting, and determined that the project did not need to come to our board for ethics review and approval since the focus of your study does not involve human subjects, but rather environmental samples. If this project should lead to further research which would involve human subjects in some format (e.g. questionnaire, interviews, human samples), then that research would need to receive review and approval from our board. We would welcome your returning at that time.

On behalf of the Health Research Ethics Board (B: Health Research), I wish you every success in your research endeavors.

Sincerely,

Sharon Warren

Dr. Sharon Warren
Chair, Health Research Ethics Board (B: Health Research)

cc: Dr. Warren Kindzierski
Mr. Steven Probert

Appendix 3

Geographical Distribution of Total School Population

EPS					EIPS	EICS
NW	NE	C	SW	SE	Elk	Elk
Abbott	Afton	Academy	Allendale	Bisset	Clover Bar	Arch Bishop
Bannerma	Brightvi	Belveder	Avalon	Brookside	Colchester	Father Kenneth Kearns
Bataryn	Britanni	Calder	Avonmore	Crawford	Fultonvale	Holy Redeemer
Beacon H	Coronati	Center H	Belgravia	D.S. Mac	Glen Allen	Madonna
Bellevue	Glendale	Delton	Capilano	Dan Knot	Mills Harmon	Our Lady of Perp. Help
Dickins	Glenora	Delwood	Clara Tyner	Earl Bux	Westboro	St. Luke
Dunluce	High Par	Inglewoo	Forest H	Edith Ro	Ardrossan Elemen.	St. Theresa
Eastglen	Hillcres	Killarne	Fulton P	Ekota	Ardrossan jr/sr	Jean Vanier
Fraser	James Gi	Lauderda	Garneau/	Ellerslier	Bev Facey	
Griesbac	Lymburn	McArthur	Grandview	George H	Brentwood	
Highland	Lynnwood	Mee-Yah-	Hardisty	Grace Ma	Campbelltown	
J.A. Fife	Mayfield	North Ed	Hazeldéa	Greenfie	F.R. Hayes	
John Barcco	Meadowla	Norwood	Kenilwore	Harry Ainley	Ministik	
Kildare	Michael	Oliver	King Edward	J. Percy	Pine Street	
Kirkness	Ormsby	Parkdale	L.Y. Cai	Julia Kiniski	Salisbury	
Lago Lind	Patricia	Prince C	L'Academy	Kameyose	Sherwood heights Jr. high	
Londondery	Rio Terr	Princeto	Lansdown	Kate Che	Uncas	
M.E. LaZ	Ross She	Queen El	McKee	Lee Ridge	Wes Hosford Elemen.	
Mary But	Sherwood	Riverdal	McKernan	Meyokumi	Woodbrid. Farms	
McLeod	Thorncli	Rosslyn	Old Scon	Meyonohk	Wye	
Mount Ro	Westlawn	Scott Ro	Ottewell	Minchau		
Newton	Westmins	Sherbroo	Parkalle	Pollard		
Northmou	Woodcrof	Spruce A	Ritchie	Rideau P		
Overland	Youngsto	Wellingt	Rutherfo	Riverbend		
R.J. Scb	Aldergro	Westglen	Strathco	Sakaw		
Rundle	Belmead	Westmount	Terrace	Satoo		
Sifton	Callingw	Athlone	Windsor	Steinhaul		
Steele	Centenni	Balwin	Donnan	Tipaskan		
Virginia	Crestwoo	Eastwood	Gold Bar	Vernon B		
York	Dovercou	Glengarr	Holyrood	Weinlos		
Belmont	Elmwood	John A.	Lendrum	Westboro		

NW	NE	EPS			EIPS	EICS
		C	SW	SE	Elk	Elk
Caernarv	Grovenor	Kensingt	Malmo	Brander Gardens		
Evansdale	Jasper P	McCauley	McNally	Daly		
Homestead	LaPerle		Mount Pl	Duggan		
Horse Hi	Laurier		Waverley	Greenview		
John D. Bracco	Parkview			Hillview		
Lawton	S. Bruce			Keheewin		
Lorelei	Talmud T			Malcolm		
Montrose	Winterbure			Menisa		
				Richard		
				T.D. Bak		
				Velma E.		
				W.P. Wagner		

EPS	Edmonton Public Schools	EIPS	Elk Island Public Schools
NW	North West	EICS	Elk island Catholic Schools
NE	North East		
C	Central		
SW	South West		
SE	South East		

Appendix 4

Two Level Stratification of Total Population

	Geographical zones or strata						
	NW	NE	C	SW	SE	Elk	Total
No water damage	9	15	7	8	12	5	66
Water damage	30	24	26	27	31	13	151
Total	39	39	33	35	43	28	217

Total population by school board	EPSB =189	ELK=28	217
%age by school board	87%	13%	

NW	North West	SW	South West
NE	North East	SE	South East
C	Central	Elk	Elk Island Schools

Appendix 5

Criteria for Selection of a Second Estimator

School Board	Grades	Utilization rate (%)	Types of Foundation	Portables/Pods
EICS	K-9 (7) 9-12	Max. 130.6 Min 74.0	Slab on grade & crawl space (4) Slab on grade (4)	No (1) Yes (7)
EIPS	k-6 (14) 7-9 (3) 7-12(1) 9-12 (2)	Max 121.7 Min. 59.3	Slab on grade & crawl space (3) Slab on grade (16) Basement & slab on grade & crawl (1)	No (9) Yes (11)
EPSB	K-6 (126) 7-9 (30) 10-12(13) K-9 (1) K-12 (1) 6-12 (1)	Max. 169.0 Min. 59.3	Slab on grade (106) Crawl space (66) Basement (21)	No (116) Yes (78)
Summary	K-6 (140) 7-9 (33) 10-12(13) K-9 (23) K-12 (1) 6-12 (1) 9-12	Max. 169.0 Min. 59.3	Slab on grade (126) Crawl space (66) Basement (21) Slab on grade & crawl space (7) Basement & slab on grade & crawl (1)	No (116) Yes (78)

EICS Elk Island Catholic School Board

EIPS Elk Island Public School Board

EPSB Edmonton Public School Board

Appendix 6

Baseline Sample

NW	C	NE	SW	SE	ELK
R1-NW-004	R1-C-007	R2-NE-037	R1-SW-005	R1-SE-006	R2-E-031
R1-NW-018	R1-C-022	R2-NE-036	R1-SW-019	R2-SE-039	R1-E-002
R2-NW-038	R2-C-025	R1-NE-003	R2-SW-026	R2-SE-042	R1-E-023
R2-NW-034	R1-C-015	R1-NE-008	R2-SW-035	R1-SE-001	R2-E-030
R2-NW-024	R2-C-041	R1-NE-014	R1-SW-016	R2-SE-020	R1-E-009
R2-NW-043		R2-NE-028	R1-SW-017	R2-SE-029	R2-E-032
		R2-NE-027		R1-SE-011	R1-E-010
				R1-SE-013	R2-E-033
					R2-E-040
					R1-E-012
					R2-E-021
6 Schools	5 Schools	7 Schools	6 Schools	8 Schools	11 Schools

NW North West

NE North East

C Central

R1 Round 1

R2 Round 2

SW South West

SE South East

EIK Elk Island Schools

Appendix 7

Subset Sample

Within Space	Seasonality	Within Phase/ Structures	CO2 Decay
R1-NE-008	R1-SE-001	R2-E-031	R1-SE-011
R1-NW-018	R1-C-007	R1-NE-014	R2-SE-029
R1-C-015	R1-SE-011	R1-C-015	R2-NW-034
R1-SE-013	R2-E-021	R2-NW-024	R2-SW-035
R1-SW-016	R1-NE-014	R2-NE-037	R2-SE-042
R1-SW-019	R1-E-002	R2-SE-039	R2-SE-020
R1-E-009	R1-SE-006	R2-E-021	R2-NE-027
R1-C-022	R1-NW-004	R2-NW-038	R2-C-025
R1-E-010	R2-SE-020	R2-SE-042	
	R1-NE-003		

NW North West

NE North East

C Central

R1 Round 1

R2 Round 2

SW South West

SE South East

EIK Elk Island Schools

Appendix 8

Sampling Schedule

1.0 Major equipment requirements.

- 2 Q-Traks, (for simultaneous outdoor & indoor sampling)
- 2 RCSplus (for simultaneous outdoor & indoor sampling)
- 1 Velocicalc
- 1 Vehicle
- 3 investigators (#1, #2, #3)

2.0 Major premise

Complete one school per day, monitoring 10% of randomly selected rooms within the school and their associated air handling units.

With both sampling schedules, a total of 35 schools can be sampled over a period of 30 days.

Q- Trak a will be stationary in one room for 6-8 hours, while Q- Trak b will be a rover, spending 15 minutes at all other locations.

3.0 Approximate Time line

Time	Activity
7:45 - 8:30 am	• #1, #2, #3 drive to school being sampled
8:30 - 9:00 am	• #1, #2, #3 sign in at the main office, making contact with the principal & facility personnel.
9:00 - 12:00 am	• #1, #2, #3 tour air handling units with facility personnel*
9:00 - 12:00 am	• #2 will set up Q- Trak a in one room to be surveyed for 6-8 hrs. • #1, #2, #3 visit each room being sampled. • Introduction to teacher and class • Set up & measure Q- Trak b for 15 mins, and RCSplus for 6 mins. • Label samples and record data in IAQ Log Book. • Complete room surveys. • Disinfect RCSplus with alcohol wipes in between rooms. • If time permits #2, #3, will complete control sample outdoors in front of main entrance (otherwise to be completed as the last component before signing out of school)
12:00 - 1:00 pm	While students are not in class, #1, #2, #3 will measure the (lunch break) ventilation rates of all SA vents in each room with Velocicalc, using a 6ft ladder
1:00 - 2:30 pm	#1, #2, #3 will all sample the OAIs with the RCSplus, Velocicalc and, Q- Trak b

	2:30 pm ., #2, #3 sign out of the school.
2:30 pm	2:30 pm ., #1, #2, #3 sign out of the school. #1, #2, #3 ensure that all samples are well labelled, and that the are laced into the locked trunk of the car
4:30-5:00 pm	• ., #2, #3 drive to UofA mycology lab to deposit air, bulk & surface samples
5:00-5:45 pm	• . downloads information from Velocicalc & Q-Trak onto floppy and hard drive making certain data is valid. • #2 & #3 prepare for the next day of sampling, ensuring all equipment & surveys are accounted for: Velocicalc, Q-Traks, RCSplus, RBA strips, baggies, wax paper, transparent tape, clipboards, map of Edmonton, map of Strathcona County including Sherwood Park, HVAC survey, room survey, ID cards, sealed boxes, information sheets, signed copy of the principal consent sheets

† Vehicle to be picked up at the UofA rental pool.

Appendix 9 Information letters

Information letter sent to Edmonton Public School Board



Environmental Health Services

December 9, 2002

Dear Ms. Johnston,



UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

Capital Health Authority, Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools are in partnership with the University of Alberta to investigate indoor air quality in schools. Mary Unobe, Lorelei Betke, Corinne Stocco and are University of Alberta graduate students under the supervision of Dr. Warren Kindzierski.

Please find attached the names of 26 Edmonton Public Schools that have been randomly selected for investigation. Depending on available resources, it may be possible to sample more schools. The purpose of this study is to determine the current quality of indoor air within these schools and to develop management strategies to ensure the ongoing maintenance of acceptable air quality. This investigation will include building inspections and monitoring of mould, carbon dioxide, carbon monoxide, temperature, relative humidity and ventilation rates.

As part of this study, we are requesting the assistance of facilities service's personnel who are familiar with heating and ventilation (HVAC) systems of the selected schools. For each selected school, these personnel are asked to complete a *School Screening Survey* by August 24th and a *School Maintenance Survey* by **September 10th**, requiring approximately 25 minutes each. During each sampling round, the field investigators will also require the assistance of facilities personnel to conduct an inspection of the heating and ventilation system, requiring approximately two hours per school. It is anticipated that there will be a total of three sampling rounds, which is about nine schools per round.

To assist the field investigators in gathering the necessary information for the study and to help schedule field visits, please complete the attached *Facilities Services Response Form* by **August 24, 2001**. Thank you in advance for your participation and cooperation.

Yours truly,

Dr. Warren Kindzierski
University of Alberta

Dr. Gerald Predy
Medical Health Officer

Cc: Angus McBeath, Acting Superintendent of Schools
Dick Divine, Facilities Operations, Facilities Services
Cynthia Wilson, Personnel Support Services
Brian Fedor- Managing Director, Facilities Services

Information letter sent to Elk Island Public School



Capital
Health

Environmental Health Services



UNIVERSITY OF ALBERTA

Civil and Environmental Engineering

December 9, 2002

Robert McPhee
Superintendent of Schools
Elk Island Public Schools

Dear Mr. McPhee

Capital Health Authority, Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools are in partnership with the University of Alberta to investigate indoor air quality in schools. Mary Unobe, Lorelei Betke and Corinne Stocco and Mary Unobe are University of Alberta graduate students under the supervision of Dr. Warren Kindzierski.

Please find attached the names of 4 Elk Island Public Schools that have been randomly selected for investigation. The purpose of this study is to determine the current quality of indoor air within these schools and to develop management strategies to ensure the ongoing maintenance of acceptable air quality. This investigation will include building inspections and monitoring of mould, carbon dioxide, carbon monoxide, temperature, relative humidity and ventilation rates.

As part of this study, we are requesting the assistance of facilities service's personnel who are familiar with heating and ventilation (HVAC) systems of the selected schools. For each selected school, these personnel are asked to complete a *School Screening Survey* by August 24th and a *School Maintenance Survey* by **September 10th**, requiring approximately 25 minutes each. During each sampling round, the field investigators will also require the assistance of a facilities personnel to conduct an inspection of the heating and ventilation system, requiring approximately two hours per school. It is anticipated that there will be a total of three sampling rounds.

To assist the field investigators in gathering the necessary information for the study and to help schedule field visits, please complete the attached *Facilities Services Response Form* by **August 24, 2001**. If you have any questions or concerns, please contact Mary Unobe at 492-8548. Thank you in advance for your participation and cooperation.

Yours truly,

Dr. Warren Kindzierski
University of Alberta

Dr. Gerald Predy
Medical Health Officer

Cc: Brian Smith, Associate Superintendent, Business Services, Elk
Island Public Schools

Capital
Health

Environmental Health Services



UNIVERSITY OF ALBERTA

Civil and Environmental Engineering

Facility Response Form

Title of Project:

Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.

Principal Investigators:

Steven Probert
Capital Health
(780) 413-7933Warren Kindzierski
University of Alberta
(780) 492-0247

Co-Investigators:

Lisa Johnston
Edmonton Public Schools
(780) 429-8132Dale Lechelt
Elk Island Public Schools
(780) 417-8125Steve Hayes
Elk Island Catholic Schools
(780) 467-8896

Field Investigators:

Mary Unobe, Lorelei Betke and Corinne Stocco
University of Alberta (780) 492-8548 or
(munobe@ualberta.ca).

Please complete the following form and fax it by September 5, 2001 to:

Name: IAQ Investigation

C/o Dr. Kindzierski

University of Alberta

FAX # (780) 492-8289

Telephone # (780) 492-8548

Questions 1-2 of this form will help the investigators to schedule their visit. Please read the paragraph at the bottom of page 2 carefully as this pertains to obtaining consent. Upon receipt of this form, the investigators will contract you by phone to confirm inspection date and time.

The three sampling rounds will occur from:

1. September 17th - October 19th, 2001
2. December 3rd - 21st, 2001 & January 7th - 18th, 2002
3. February 18th - March 22nd, 2002

1. For scheduling purposes, please attach a calendar indicating any personal holidays and other days in which you would not be available for an onsite meeting. Using this calendar, the investigators will contact you to schedule a date and time for the HV AC inspection

2. Please list any questions, comments or concerns:

3. I understand that by signing below, I will be participating in the indoor air quality investigation that is being completed by Capital Health Authority and the University of Alberta. I know that I am in no way obligated to participate, and that I have the right to withdraw at any time within the study, without consequence. I have received and read a copy of the information sheet, and have had an opportunity to ask an investigator my questions. I also understand that all data that will be obtained during this study will be kept private. Information from this study will be kept for at least five years in a secure area. It is possible that the data may be looked at again in the future to help answer other study questions.

I agree to participate in the study:

Name

Signature

Title

Date

To the Principal

Title of Project: *Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.*

Principal Investigators: Steven Probert Warren Kindzierski
Capital Health University of Alberta
(780) 413-7933 (780) 492-0247

Co-Investigators: Lisa Johnston Dale Lechelt
Edmonton Public Schools Elk Island Public Schools
(780) 429-8132 (780) 417-8125

Steve Hayes
Elk Island Catholic Schools
(780) 467-8896

Field Investigators: Mary Unobe, Lorelei Betke and Corinne Stocco
University of Alberta (780) 492-8548 or
(munobe@ualberta.ca)

Capital Health Authority, Edmonton Public Schools, Elk Island Public and Elk Island Catholic Schools are in partnership with the University of Alberta to investigate indoor air quality in the Capital Health Region Schools. The investigators Mary Unobe, Lorelei Betke and Corinne Stocco, are Master's students in the Department of Environmental Engineering and Science, and are under the supervision of Dr. Warren Kindzierski.

Although it is not believed that there is a widespread air quality problem in schools, the purpose of this proactive study is to determine the status of indoor air quality in schools and to help identify issues and appropriate management strategies to maintain acceptable air quality.

Your school has been invited to participate in this study, which will be at no cost to the school. This investigation will consist of a building inspection, collection of air and surface samples for mould, and measurement of temperature, carbon dioxide, carbon monoxide, relative humidity, and ventilation rate.

In order to obtain accurate measurements, it is essential that sampling occur under normal activity levels during regular school hours, with ventilation systems operating. There will be at least two visits to your school; one between mid-September and mid-October and one between mid-February and March. A third visit to your school may occur in December or January. Each visit will last about half a day.

The investigators will contact you at least two weeks before sampling begins. For each visit, the investigators will report to the main office for direction. On the initial visit, investigators and a district facilities representative will meet with the head custodian for 1 hour to conduct an inspection and answer questions about the school ventilation system.

The school's investigative result will be made available to Facilities Services and a final report on all schools will be completed in May 2002. If the investigators discover any concerns of a serious or imminent nature in your school, yourself and facilities Services will be notified immediately. All the information gathered in this study will be held confidential except when professional codes of ethics or law require reporting.

Find enclosed a response form that will help schedule school sampling activities. Please complete and return the enclosed forms by September 5, 2001. If you choose to participate in this study, the date of sampling will be confirmed via phone before September 10, 2001.

If you have any concern or questions, please feel free to contact the field investigators at 492-8548. Thank you in advance for your participation and co-operation.

Dr. Terry Gunderson (EIPS) or Dr Douglas Aitkenhead (EICS) or Dr MacBeath (EPS)
School Supritendent.

Dr. Warren Kindzierski
University of Alberta

Dr. Gerald Predy
Medical Health Officer

Cc: Head Custodian

INDOOR AIR QUALITY IN EDMONTON AND ELK ISLAND PUBLIC AND CATHOLIC SCHOOLS

INFORMATION SHEET

What is the purpose of the project?

Maintenance of high indoor air quality is an important consideration in a school environment. Recently, mould has been investigated as a potential cause of health concerns such as sneezing, coughing and eye irritation.

This study will examine the indoor air quality (IAQ) of schools, with particular focus given to the presence of mould and its contributors such as humidity and temperature.

What information will be gathered?

Information will be gathered from visual inspection and sampling of air for IAQ parameters such as carbon dioxide, carbon monoxide and fungal spores. Temperature and humidity will also be assessed.

Investigators will also collect information regarding the school mechanical systems as well as general information regarding school renovations and episodes of water damage.

What will be done with the information gathered?

The information collected will be maintained in an electronic database. Air samples will be evaluated by the Provincial Public Health Laboratory at the University of Alberta. Results from

the study will be included in a final report to The Capital Health Authority.

The information collected will not be of a personal nature. Students will not be approached to assist in any way.

Who is conducting the study?

Capital Health Authority is coordinating the study in cooperation with the Edmonton Public School Board, and the Elk Island Public and Catholic School Boards. Graduate students from the University of Alberta will conduct the field investigation.

When does it start and how long will it take?

The entire project will take about one year to complete. Estimated sampling time frames at individual sites are approximately half a day. Sampling will be conducted in September/October, December/January and in February/March. A final report will be completed by May, 2002.

What community benefits may arise from this study?

Possible benefits arising from this study include:

- Healthier children and teachers
- Emphasizing proactive management of school IAQ

- Making school staff and the public aware of poor IAQ and its effects

Where can I get more information on the study?

Questions may be directed to any of the investigators listed below.

Principal Investigators:

Dr. Warren Kindzierski
Assistant Professor
University of Alberta
(780) 492-0247

Steven Probert
Capital Health Authority
(780) 413-7933

Co-Investigators

Lisa Johnston
Edmonton Public Schools
(780) 429-8132

Dale Lechelt
Elk Island Public Schools
(780) 417-8125

Steven Hayes
Elk Island Catholic Schools
(780) 467-8896

Field Investigators:

Mary Unobe/Corinne Stocco/Lorelei Betke
Graduate Students
University of Alberta
492-3576

Capital
Health

Environmental Health Services



UNIVERSITY OF ALBERTA

Civil and Environmental Engineering

Principal Response /Consent Form

Title of Project:

*Indoor Air Quality in Edmonton Public Schools, Elk
Island Public Schools and Elk Island Catholic Schools.***Principal Investigators:**Steven Probert
Capital Health
(780) 413-7933Warren Kindzierski
University of Alberta
(780) 492-0247**Co-Investigators:**Lisa Johnston
Edmonton Public Schools
(780) 429-8132Dale Lechelt
Elk Island Public Schools
(780) 417-8125Steve Hayes
Elk Island Catholic Schools
(780) 467-8896**Field Investigators:**Mary Unobe, Lorelei Betke and Corinne Stocco
University of Alberta (780) 492-8548 or
(munobe@ualberta.ca).**Instructions:**

The requested information will provide the principal's consent to participate in the study and enable the investigators to schedule their visit in either fall 2001 or winter 2002. If you need additional information to assist you in making this decision, please call your school board's co-investigator or Capital Health's principal investigator identified above.

Please complete and return this form via facsimile by September 14, 2001 to:

School IAQ Study
Warren Kindzierski
University of Alberta
FAX # (780) 492-8289

After receiving the completed form, the investigators will contact you to schedule their visit. Thank-you for your co-operation.

School Name: _____	
Street Address: _____	Postal Code: _____
Phone No.: _____	Fax No.: _____

1. If you agree to participate, please read the below paragraph and indicate your consent by signing below.

I understand that by signing below, my school will be participating in the indoor air quality investigation that is being completed by Capital Health and the University of Alberta. I know that my school is in no way obligated to participate, and that I have the right to withdraw at any time during the study, without consequence. I have received and read a copy of the information sheet, and have had the opportunity to ask an investigator my questions. I also understand that all data that will be obtained during this study will be kept confidential and will be kept for at least five years in a secure area. I also know that it is possible that the data obtained from the investigation may be looked at again in the future to help answer other study questions.

I agree to allow this school to participate in the study:

Principal's Name

Date

Principal's Signature

2. In order to facilitate scheduling, please attach a school calendar indicating any holidays, PD Days and other days in which 'normal' room activities may not be occurring in the sample locations (e.g., fieldtrips, school assemblies). If this calendar is not yet available, please fax the response form without it, and the investigators will be as flexible as possible during scheduling.

3. In order to facilitate HVAC investigations, please provide the following information:

Head Custodian's Name _____

Head Custodian's Phone Number _____

4. Please list any questions, comments or concerns:

INDOOR AIR QUALITY INVESTIGATION RESPONSE FORM

Please complete the following form and return it by September 5, 2001 to:

Name: IAQ Investigation
c/o Dr. Kindzierski

FAX # (780) 492-8289
Phone # (780) 492-3576

Your cooperation in completing this form and returning it is appreciated. This will enable the investigators to make up the schedule for their visits. Confirmation of visit to your school will be sent to you in writing by September 10, 2001.

1. School name _____
Address _____
Phone number _____ Fax number _____
2. Facilities Coordinator's name _____
Phone number _____
3. Please indicate the times when students are in the school
(ex : 8:30-11:30am and 12:30-3:30pm)

4. Below is a list of all possible days in which sampling can take place. Please cross out days or weeks that are not appropriate due to professional development days when students are not at school, and normal activity is not occurring.

Sampling Round	Week of Sampling	Cross out days-weeks not applicable (eg. PD Day)				
1	Sept 17 - 21, 2001	M	T	W	Th	F
	Sept 24 - 28, 2001	M	T	W	Th	F
	Oct 1 - 5, 2001	M	T	W	Th	F
	Oct 8 - 12, 2001	☒	T	W	Th	F
	Oct 15 - 19, 2001	M	T	W	Th	F
2	Dec 3 - 7, 2001	M	T	W	Th	F
	Dec 10 - 14, 2001	M	T	W	Th	F
	Dec 17 - 21, 2001	M	T	W	Th	F
	Jan 7 - 11, 2001	M	T	W	Th	F
	Jan 14 - 18, 2001	M	T	W	Th	F
3	Feb 18 - 22, 2002	M	T	W	Th	F
	Feb 25 - Mar 1, 2002	M	T	W	Th	F
	Mar 4 - 8, 2002	M	T	W	Th	F
	Mar 11 - 15, 2002	M	T	W	Th	F
	Mar 18 - 22, 2002	M	T	W	Th	F

Signature _____

Title _____

Environmental Health Services

Civil and Environmental Engineering

Appendix 14 Pre-Screening Questionnaire

Title of Project: **Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.**

Principal Investigators: **Steven Probert** **Warren**
Kindzierski **Capital Health** **University of**
Alberta **(780) 413-7933** **(780) 492-0247**

Co-Investigators: **Lisa Johnston** **Dale Lechelt**
 Edmonton Public Schools **Elk Island Public Schools**
 (780) 429-8132 **(780) 417-8125**

 Paul Steinhubl
 Elk Island Catholic Schools
 (780) 467-8896

Field Investigators **Mary Unobe, Corinne Stocco, Lorelei Betke**
 University of Alberta
 (780) 492 – 8548 or (munobe@ualberta.ca)

Background Information:

Capital Health and the University are investigating the quality of indoor air within public schools. The Project will measure certain indoor air quality parameters (fungal aerosols and ventilation rates) and determine building designs and conditions that may contribute to indoor air quality. The results of this questionnaire will assist the investigators in selecting a representative sample of your schools.

Instructions:

This questionnaire is to be completed by a qualified person designated by your school board's co-investigator, as listed above. Please answer all of the questions by printing in the spaces provided or placing a checkmark in the correct box. Please contact your co-investigator or Steven Probert for assistance. The completed questionnaire is to be returned to your co-investigator **by May 23, 2001.**

Name of School: _____
Street Address: _____ Postal Code: _____
Circle City/County: Edmonton Sherwood Park Strathcona County

Who completed this questionnaire?

Name: _____ Phone No.: _____

Name: _____ Phone No.: _____

1. What category does the school fall into?

K-6: ☐ K-9: ☐ K-12: ☐ 6-9: ☐ 6-12: ☐
9-12: ☐

2. What type of foundation(s) is/are found in school excluding portables/pods? (Please check all that apply)

Basement: ☐ Slab-On-Grade: ☐
Crawl Space: ☐

3. What year did the initial construction of school take place?

4. Are portables and/or pods present?

Yes: ☐ No: ☐

5. Does school have a forced air ventilation system?

Yes: ☐ No: ☐

6. Has school ever had a modernization (as defined in the 1997 draft of the School Capital Plan) and/or a heating and ventilation system upgrade?

Yes: ☐ No: ☐

7. In the past 5 years, has the school had a history of water damage (e.g. roof leak, plumbing leak, poor surface drainage around buildings)?

Yes: ☐ No: ☐

8. In the past 5 years, has the school had an investigation of IAQ concerns?

Yes: ☐

No: ☐

9. In the past 5 years, has the school ever had to take actions to resolve fungal (eg. Mold, mildew) contamination concerns?

Yes: ☐

No: ☐



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Civil and Environmental Engineering

School Maintenance History Questionnaire

Title of Project: Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.

Principal Investigators: Steven Probert
Capital Health
(780) 413-7933

Warren Kindzierski
University of Alberta
(780) 492-0247

Co-Investigators: Lisa Johnston
Edmonton Public Schools
(780) 429-8132

Dale Lechelt
Elk Island Public Schools
(780) 417-8125

Paul Steinhubl
Elk Island Catholic Schools
(780) 467-8896

Field Investigators Mary Unobe, Corinne Stocco, Lorelei Betke
University of Alberta
(780) 492 - 8548 or (munobe@ualberta.ca)

Instructions:

The purpose of this questionnaire is to determine episodes of water damage and recent renovations/upgrades in the school. Maintenance of school mechanical systems will also be assessed and incidence of air quality complaints evaluated. This will assist investigators in the interpretation of sampling results gathered from the various locations in the school.

This school maintenance history survey is to be completed for selected schools by a facilities personnel offsite. It may be most convenient to complete this survey in conjunction with the School Screening Survey since both are completed offsite and are looking for related information.

There are four main questions in this survey, as well as a schematic of the school floor plan that has been included for reference purposes. Please answer all questions by printing in the appropriate boxes. If a question is unclear, please contact a field investigator for assistance. Return to investigators by September 15. Thank-you for your cooperation.

Who completed this questionnaire? Name: _____
Phone No.: _____

A. School Maintenance History:

1. Complete the table with any incidents of major water damage that occurred within the past five years:

Incident	Phase Number(s)	Room Number(s)	Year of Incident	Was incident resolved? (Yes/No/N/A)	Year Resolved
Roof Leak					
Sewer or Water Main Break					
Surface Drainage Leak					
Other (please describe) _____ _____					

2. Indicate if the following renovations/upgrades occurred within the past five years:

Renovation/Upgrade	Year of work	Phase Number(s)	Room Number(s)
Adjustment to Room Size			
Open Room Enclosed			
Room Conversion			
Other (please describe) _____ _____			

3. Please answer the following set of questions:

a) How often is the HVAC system balanced?

On a routine basis: ☐

As needed: ☐

b) Is there a preventative maintenance program for the HVAC system?

Yes: ☐

No: ☐

If so, is there a method to assess the effectiveness of the HVAC maintenance program?

Yes: ☐

No: ☐

c) Are the air ducts professionally cleaned on a routine basis?

Yes: ☐

No: ☐

Unknown: ☐

d) When were the air ducts last professionally cleaned?

2001 ☐

2000 ☐

1999 ☐

Unknown ☐

Other ☐

If other, indicate year of cleaning _____

4. Please answer the following questions:

a) In the past five years, have the school staff, parents or students reported any concerns about the school's indoor air quality?

Yes ☐

No ☐

b) In the past year, approximately how many of these individuals have reported indoor air quality concerns?

1-10 ☐

11-30 ☐

31-50 ☐

>50 ☐

Glossary of terms for the School Maintenance History Survey

Term	Definition
Air balancing	The process of measuring the distribution of air supply and the amounts of exhausted air.
Ducts	Conduits through which supply air travels.
Heating, ventilation and air conditioning (HVAC)	Air handling systems designed primarily for temperature, humidity, odour control, and air quality.
Major Water Damage	Damage that occurs repeatedly
Preventative maintenance	Pro-active steps to prevent problems for the HVAC system (eg. cleaning schedule).



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Civil and Environmental Engineering

School Screening Questionnaire

Title of Project: Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.

Principal Investigators:

Steven Probert
Capital Health
(780) 413-7933

Warren Kindzierski
University of Alberta
(780) 492-0247

Co-Investigators:

Lisa Johnston
Edmonton Public Schools
(780) 429-8132

Dale Lechelt
Elk Island Public Schools
(780) 417-8125

Arjen Devries
Elk Island Catholic Schools
(780) 467-8896

Field Investigators

Mary Unobe, Corinne Stocco, Lorelei Betke
University of Alberta
(780) 492 - 8548 or (munobe@ualberta.ca)

Instructions:

This survey will enable investigators to select rooms in your school for sampling of indoor air quality parameters. If a question is unclear, please refer to the glossary of terms or contact one of the field investigators for assistance. Thank-you for your co-operation.

This survey is to be completed by a qualified person appointed by the school board co-investigators listed above. The completed survey is to be submitted to your co-investigator by August 24th, 2001.

Please begin by obtaining a schematic of the school floor plan that identifies all rooms by number and function. This schematic should be stapled to the back of this survey. Outline each 'construction phase' in red and identify it as Phase I, II, III, IV, etc. Each portable or pod should be identified as a separate 'construction phase'. Rooms with a history of water damage and/or visible or suspected fungal growth should be indicated with an asterisk (*), as shown in the sample schematic.

Please complete the attached Screening Survey for each 'construction phase', answering all questions by placing a check mark or appropriate number in the correct box(es). If there is more than one correct box, check all that apply.

Who completed this questionnaire?

Name:

Phone no.

Name:

Phone no.

Date of completion (dd/mm/yy)

Sample Schematic

Phase I					Phase II		
101*	102*	103	104		201		
105*	106	107	108	109	203	202	
110	111	112	113	114		204	
115	116				301	401	
117	118	GYM 119			302	402	403
					303		

Phase III

Phase IV

1*

P-2*

P - 3	P - 4
P - 5	P - 6

Phase V

Phase VI

Phase VII

(potable)

(portable)

(pod)

*Denotes rooms that have had fungal investigations and /or water damage.

[illegible][illegible][illegible]

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Terms	Definition
Construction Phase	A stage in the development of the project that occurs after the construction contract has been awarded and until the certificate of substantial completion has been issued.
HV AC System	These are systems that service multiple rooms and exclude unit serving a single room (eg. unit ventilator, small forced-air furnace in a pod or portable). Please use the school's identifier, or room numbers that they service.
Masonry	Stone-work, other than brick.
Permanent	The main school building structure that cannot easily be relocated.
Pod	This is typically one unit that has several classrooms within it. It may or may not be connected to the permanent building structure via hallways.
Portable	This is typically a one classroom unit which has its own. This structure may or may not be attached to the permanent building structure via hallways, and can be relocated to other locations.
Suspected mould growth	Musty smells.
Visible mould growth	>0.5 square foot of mould For example: ceiling tiles, Ductwork, wallboard panels.
Water damage	Damage that occurs repeatedly. For example: roof leak, water main break, and surface drainage leak.

* Based on the 2001 Alberta Infrastructure Guidelines.



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HVAC SURVEY

Name of school: _____ Date: _____

1. Answer the following questions regarding the air handling system identified below:

Air handling system ID	
Type of ventilation system	Hot water boiler ☐ Steam boiler: ☐ Furnace: ☐ Forced air: ☐ Unit ventilator: ☐ Roof top: ☐
Phase(s) and /or room (s) serviced	
Function	Heating: ☐ Humidifying: ☐ Cooling: ☐ Dehumidifying: ☐ Other: ☐ _____

2. Description and condition of heating, cooling and reheating coils, humidifiers and drain pans:

Description	Heating Coils	Cooling Coils	Drain Pan	Reheat Coil	Humidifier
Clean					
Slime or mould buildup*					
Clogged			--		
Other					
Not accessible					
Doors well-sealed?	Yes ☐ No ☐	Yes ☐ No ☐	--	--	--

*take tape sample

3. Questions pertaining to indoor / outdoor air mixing:

Appearance of main mixing box	Clean ☐ Dry ☐ Dirty ☐ Wet ☐ No access ☐
Control of mixing box	Pneumatic ☐ DDC ☐ Other ☐
Indoor : Outdoor mixing ratio	
Outdoor delivery at all times?	Yes ☐ No ☐

4. Filter type and condition:

Dual stage filter?	Yes ☐	No ☐
Filter type	Box filter ☐	Bag filter ☐ Roll filter ☐ HEPA ☐
	Other ☐	
Condition of filter	Clean ☐	Build up ☐ Clogged ☐
Tight fitting filter?	Yes ☐	No ☐
Magnehelix reading	< 1 ☐	1 - 1.5 ☐ >1.5 ☐

5. Description of outdoor air intake (OAI) & surrounding areas.

Obstructed?	Yes ☐	No ☐
Bird screen?	Yes ☐	No ☐
Insect screen?	Yes ☐	No ☐
Sources of CO?	Yes ☐	No ☐
Protection from rain/snow?	Yes ☐	No ☐
Evidence of standing water?	Yes ☐	No ☐
Sources of contamination?	Yes ☐	No ☐
Distance between exhaust and intake	0-10 ft ☐	>10 ft ☐

6. General condition of the system:

Water collecting anywhere except the drain pan?	Yes ☐	No ☐
Complete air handling shutdown?	Evenings ☐	Weekends ☐ N/A ☐
Partial air handling shutdown	Evenings ☐	Weekends ☐ N/A ☐
Self regulated	Yes ☐	No ☐
Mechanical room cleanliness	Chemical storage Yes ☐ No ☐	Clean Yes ☐ No ☐
Supply fan operating?*	Yes ☐	No ☐ Unknown ☐
Exhaust fan operating?*	Yes ☐	No ☐ Unknown ☐

Comments:

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Environmental Health Services

Civil and Environmental Engineering

ROOM SURVEY

Name of School: _____

Date completed _____

Survey Information		Comments
General information		
1	Construction phase	
2	Room #	
3	Room volume (ft ³)	$V = L * W * H =$
4	Number of occupants in the room (other than investigators):	0 ☐ 1-10 ☐ 11-20 ☐ 1-30 ☐ >31 ☐
5	Function of the room?	Classroom ☐ Gym ☐ Music Room ☐ Food Studies ☐ Lab ☐ Other ☐
6	Level of room activity	Low ☐ High ☐ None ☐
7	Is there a noticeable odour?	Yes ☐ No ☐
8	List number of plants in the room	
9a	Is there a carpet in the room?	Yes ☐ No ☐
9b	If yes, describe its condition	Good ☐ Worn ☐ Dirty ☐ Other ☐
9c	Estimate area of coverage	< 100 ft ² ☐ 100 - 200 ft ² ☐ > 200 ft ² ☐
Heating and Ventilation		
10	Sources of room ventilation	Central HVAC: Yes ☐ No ☐ Windows: Open ☐ Closed ☐ N/A ☐ Doors: Open ☐ Closed ☐ Unit Ventilator: On ☐ Off ☐ Auto ☐ N/A ☐ Local Exhaust: On ☐ Off ☐ Auto ☐ N/A ☐
11a	Is there an outdoor air intake?	Yes ☐ No ☐
11b	Condition of OAI?	Clean ☐ Partially matted ☐ Clogged ☐ N/A ☐

Potential Sources of Contamination		
12a	Is there a portable humidifier?	Yes ☐ No ☐
12b	Condition of portable humidifier	Clean ☐ Mineral Buildup ☐ Mould ☐ Growth ☐ Other ☐ _____
13	Air freshener present?	Yes ☐ No ☐
14a	Any pets in the classroom?	Yes ☐ No ☐
14b	If yes describe	_____
15	Is the classroom dusty?	Yes ☐ No ☐ Somewhat ☐
16	Are there sources of CO ₂ other than human breath?	Yes ☐ No ☐ Describe _____
17	Indicate ventilation sources (Provide schematic) CW = closed window OW = open window CD = closed door OD = open door FH = fume hood H = heater	_____
18	Additional comments	_____ _____ _____ _____

19. Using the legend below, complete the following table for evidence of water damage:

LEGEND	
A:	< 1 square foot
B:	1 – 10 square feet
C:	> 10 square feet

Area	Water Evidence (✓)				Area Type and Size (A, B, C)				Visible Mould (✓)	Sample taken (✓)
	Dry Stain	Wet Stain	Condensation	Ponding	Ceiling	Floor	Wall	Window		
1										
2										
3										
4										
5										



Capital
Health

Environmental Health Services



UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

CONDUCT PROTOCOL

Title of Project: *Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.*

PRIOR TO SCHOOL VISIT

By mid-September, mail the following to selected schools:

- Principal Information Letter
- Information Sheet
- Response/Consent form
- Conduct Protocol

In late-September, complete the following tasks,

- Phone call to set up sampling appointment with school
- Establish school contact person (Principal or designate)
- Establish facilities contact person with each project co-investigator (Dale, Lisa, Steve)
- Outline time requirements
- Outline sampling procedure
- Finalize school visits schedule

DAY BEFORE SCHOOL VISIT

- Phone call to school's contact person to confirm visit
- Phone call to facilities services' contact person to confirm meeting time and place for HVAC survey

DAY OF SCHOOL VISIT

Upon Arrival

- Ensure visible placement of identification tags
- Sign in at main office
- Introduce self to school personnel
- Meet up with school contact person & facilities contact person
- Explanation of visit to school contact person and facilities contact person

Heating Ventilation and Air Conditioning (HVAC) Survey

Inspect HVAC system and complete survey with assistance of facilities contact person

Room Survey

Introduce self to teacher/staff member in each room to be sampled and outline sampling procedure. If requested, briefly explain purpose of study
Set up equipment while minimizing room disruption
Sampling to be conducted as per *Sampling Protocol*
Remove equipment and quietly exit room

Outdoor Sampling

Access appropriate outdoor air intakes
Sampling to be conducted as per sampling protocol

Leaving School

Sign out at main office, and thank contact person for time/assistance
Advise Capital Health and school board's co-investigator of any concerns of a serious or imminent nature (protocol to be developed).

AFTER VISIT

Provide school co-investigators with preliminary sampling results as they become available for each school.
Distribute thank-you notes to schools that participated



Environmental Health Services

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering**FIELD INVESTIGATION SAMPLING PROTOCOL**

Title of Project: *Indoor Air Quality in Edmonton Public Schools, Elk Island Public Schools and Elk Island Catholic Schools.*

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Introduction

This section outlines the general field investigation and sampling protocols. Specific details regarding instrument calibration and sampling procedures are contained in the standard operating procedures for each instrument. Three instruments, namely the RCS plus fungal sampler, the Q-Trak air quality meter and the Velocicalc plus air velocity meter will be used for sampling. The RCS plus will be used to establish baseline fungal levels within sampling locations. 6-minute samples will be taken and then analyzed at the Provincial Mycological Laboratory. The Q-Trak will be used to measure CO₂, CO, relative humidity and temperature. Values of CO₂ obtained will be used for comparative analysis with established standard such as ASHRAE. Ventilation rates can also be determined from CO₂ decay measurements. The Velocicalc plus will be used to establish airflow rate measurements into the OAI as well air velocity from the diffusers located in the classrooms. Outdoor measurements with all three instruments will serve as a control for the indoor measurements in order to confirm the indoor air quality of the rooms.

GENERAL

1.0 Documentation

- 1.1 Photograph rooms being sampled and areas of noticeable fungal contamination for reference and documentation purposes.
- 1.2 When completing the room survey, note number of room occupants, and describe potential interferences to air sampling and where they are located (eg distance of heat sources to instruments and distance of instruments from occupants).
- 1.3 Store all records in a secure location (pictures, Q-Trak measurements, surveys).

2.0 QA/QC Procedures and Calibration

- 2.1 Sample during normal classroom hours.
- 2.2 Calibrate all three instruments (Q-Trak, Velocicalc plus, RCS plus) prior to sampling.
- 2.3 Calibrate RCS plus once per month.
- 2.4 Conduct one field blank per week for fungal samples only. Collect field blanks by placing the agar strip in the RCS plus and immediately removing it for laboratory analysis. The RCS plus sampler must not be operational during this procedure.
- 2.5 Duplicate 15 minutes spot sample with the RCS plus sampler once a day and field blank once a week.
- 2.6 Duplicate airflow rate measurement using the velocal plus in one space per week.
- 2.7 Duplicate Q-track sample once a week
- 2.8 Decontaminate RCS plus sampler once per week in sterile environment.
- 2.9 Include Chain of Custody forms with all fungal samples submitted for laboratory analysis.
- 2.10 Store Rose Bengal Agar (RBA) strips in a refrigerator. Keep strips away from direct heat or sunlight. RBA strips have a shelf life of 2 months.

INDOOR INVESTIGATION AND SAMPLING PROTOCOL

Fill out IAQ advisory sheet if the ASHRAE threshold levels for CO₂ are exceeded as well as if potential hazardous conditions exist.

3.0 HVAC Investigation

- 3.1 Investigate ventilation system and complete the HVAC survey with facility contact personnel.
- 3.2 Make certain that the fans are shut down so that close & safe observation of filters and coils can be made.
- 3.3 If there is evidence of mould growth, take a sample according to section 5.0 for analysis by the Provincial Public Health Laboratory.

4.0 Visual inspection in selected rooms

- 4.1 Fill out the room survey. If mould growth is visible, obtain a tape sample according to section 5b for analysis by the Provincial Public Health Laboratory.
- 4.2 Take a picture of the room from the door.

5.0 Fungal Sampling

5a Water Samples (e.g., Humidifier reservoir)

5.1a If pooling of water is noticed, collect a sample in a specimen bottle for laboratory analysis.

5b Surface Samples – Clear adhesive-tape samplingⁱ

When mould is suspected, follow the steps below:

5.1b Use latex gloves when handling tape.

5.2b Label the wax paper upon which the tape will be placed with a Sharpie pen, indicating identification number. Enter the date, time, school, phase, room, and identification number into a logbook.

5.3b Remove a 3 inch strip of tape from the dispenser. Handle tape by edges only.

5.4b Collect sample by gently touching the tape to a test surface and removing the tape with a slow, steady force. A sufficient sample will appear as a light deposit on the tape. Samples with too heavy a deposit will be difficult to examine by microscope and should be discarded into biological waste container. Make note of areas where wall is porous and tape sample is difficult to obtain.

5.5b Take one blank on the first sampling day per week and submit this to the Provincial Public Health Laboratory.

5.6b Following sample collection, attach tape strips to wax paper (avoiding creases and folds).

5.7b Dispose of used latex gloves after each sample, placing them in a biological waste container.

5.8b Lay the wax paper flat in a Ziploc bag, then into the cooler for transportation to the Provincial Public Health Laboratory.

6.0 Air sampling using RCS plus

6.1 Don clean pair of disposable gloves.

6.2 Remove impeller drum and disinfect with isopropyl alcohol. Allow drum to dry.

6.3 Mark each agar strip blister pack with a unique sampling number using a Sharpie pen. 6.4 Handle agar strips by edges only. If agar is touched, strip should be discarded.

6.5 Peel back wrapper on agar strip by about 4cm and remove the agar strip. Inspect for any growth or contamination. Discard if any visible growth is observed.

6.6 Insert agar strip into the RCS plus impeller assembly with agar surface facing towards the impeller blades until impeller drum is completely enclosed and the grip tab of the agar strip protrudes by about 2cm.

*6.7 Place the RCS plus on a tripod, 3.3 ft (1 m) off the floor, near the center of the room, orient with impeller blades facing upwards towards the ceiling.

6.8 Turn instrument on to standby mode and check battery power. If battery power becomes insufficient during sampling the samples must be discarded.

6.9 Collect six-minute air samples with a sample volume of 300 L as recommended by Health Canada guidelines.

6.10 Using the grip tab, remove the agar strip from the RCS plus impeller assembly, and place the strip back into its blister pack, nutrient surface facing downwards.

6.11 Seal sides of the blister pack with tape (being careful not to cover identification label), and place the sample into a Ziploc freezer bag.

6.12 Up to 10 agar strips in sealed blister packs can be placed into one Ziploc bag.

6.13 Ziploc bags should be returned to a dark container as soon as possible after sampling. Rose Bengal agar is fungicidal with prolonged exposure to light.

6.14 After each sample, disinfect the RCS plus impeller with isopropyl alcohol & air-dry.

6.15 Upon completion, place the RCS plus back into its carrying case.

6.16 Deliver all samples to the Provincial Public Health Laboratory within 24 hours.

*If investigating within space variability, repeat steps 6.1 to 6.14 for the following locations:

- 1m away from the main door and 1m to the right (If a wall is directly to the right, place the Q-Trak 1m away to the left).
- 1m away from center of wall opposite from door

7.0 Velocicalc Plus

7.1 Using smoke tubes, determine if vent is supply or return. Note in logbook.

7.2 Place Velocicalc about 1" on the edge of the diffuser and perpendicular to the direction of air flow in order to obtain an accurate estimate of the flow rate of the incoming air from the duct.

7.3 To measure airflow rate, expose the sensor window on the Velocicalc with the orientation dimple facing upstream of the air current.

7.4 Collect replicate flow rate measurements from multiple locations in space served by each air supply diffuser or vent according to the table below:

Vent Type	Number of Measurements	Location of Measurement
Square diffuser	4	Middle plaque, center of side
Round diffuser	4	Middle cone, equally spaced
Rectangular grille (small - medium)	Varies	Middle of each 6" x 6" square
Rectangular grille (large)	Varies	Middle of each 12" x 12" square

8.0 Q-Trak Air Quality Monitor

8.1 Two Q-Traks will be used to sample randomly selected rooms. One will be used for an 8-hour measurement, the other will be used to obtain spot measurements of humidity, temperature, CO and CO₂. *Both Q-Traks will also be used to sample CO₂ decay in an unoccupied location over 2 hours.

8.2 For spot measurements, record data for 15 minutes. Place the Q-Trak 1m away from the main door and 1m to the right. If a wall is directly to the right, place the Q-Trak 1m away to the left. Ensure that the Q-Trak is placed 6.6 ft (2m) away from any occupant and in an area of the room where it will not be directly impacted by vents, dust, cold or heat sources. If this is not possible, note interferences in logbook.

8.3 Secure the Q-Trak instrument to sampling location with duct tape at an approximate height of 1m.

8.4 Record the locations of the Q-Trak in the logbook.

8.5 If possible, take measurements during periods of peak occupancy.

8.6 Record peak average values for each parameter after the sample period into the logbook. An interval of 15 minutes compares with ASHRAE standards at a height of 3.3ft (1m).

8.7 For the 8-hour sample, make certain that instrument is running off of A/C and not batteries. Furthermore, secure the handheld portion of the Q-Trak into the briefcase, and secure the briefcase to a non-moveable object (ie. Filing cabinet, desk).

8.8 Download information from Q-Trak onto a computer at the end of the day.

*For CO₂ decay subset, place the Q-Traks in 2 unoccupied classrooms according to instructions in section 8.2. Record CO₂ data for 2 hours. Ensure school ventilation system is operating during sampling period.

[†]If investigating within space variability, repeat steps 8.2 to 8.6 for the following locations:

- Near the center of the room
- 1m away from center of wall opposite from door

OUTDOOR INVESTIGATION SAMPLING PROTOCOL

Note weather, wind conditions, time of day and any outdoor activities that could affect results. Sampling during or after rain can skew outdoor data.

9.0 Outdoor Control Sampling

9.1 Obtain control sample for RCS plus and the Q-Trak for temperatures above 0°C.

9.2 Take a control sample outdoors, 5 feet from the main entrance of the school, at a height of 3.3 ft (1 m).

9.3 Sample using RCS plus and Q-Trak plus according to section 11.0 and section 13.0 respectively.

10.0 Visual inspection

10.1 Inspect the outdoor air intake surroundings and respond to questions in the HVAC survey.

10.2 After ensuring that supply fan is back on, use smoke tubes to determine if air is flowing into outdoor air intake.

10.3 If water damage or pooling exists at the base of the OAI take a water sample according to section 5a.

10.4 If mould is visible, obtain a tape sample(s) according to the information provided from section 5b.

11.0 RCS plus

11.1 Repeat steps 6.1-6.17 from indoor RCS plus air sampling

11.2 Using a tripod, place the RCS plus vertically. Take sample 1ft away from the outdoor air intake that services the room(s) being sampled.

11.3 Shield outdoor fungal air samples from direct sunlight.

12.0 Velocicalc Plus

12.1 This instrument cannot be operated at temperatures below 5°C.

12.2 Take measurements when room is unoccupied, as several air vents will likely need to be measured over desks. A ladder may be necessary. Follow safety procedures for ladders as listed in the *Portable Ladder Safety Checklist*.

12.3 Use the grid method described in section 7.0 to sample outdoor air intakes (OAI).

12.4 Download data onto a computer at the end of the day.

13.0 Q-Trak

13.1 This instrument cannot be operated at temperatures below 5 °C

13.2 Take sample near OAIs 1.6 ft (0.5 m) away from the grating.

13.3 Take 15-minute spot measurements so that results may be compared to the ASHRAE 15-minute standard.

13.4 Download data onto a computer at the end of the day.

14.0 End of Day

14.1 Deposit tape and water samples for analysis at the Provincial Public Health Laboratory

14.2 Obtain signature of receipt on Chain of Custody form.

14.3 Decontaminate sample containers with isopropyl alcohol in the staging area of EENV building.

14.4 Ensure all data has been successfully downloaded to computer.

14.5 Prepare investigation tools for next day.

Velocicalc Plus Air Velocity Meter

1. Press the **ON** key to turn on the velocicalc plus and press arrows to scroll down until velocity/flow rate reading is obtained. Then enter.
2. Select test ID and enter.
3. Slide switch '1' into upward position to turn on the back lighter if this is desired.
4. Press **velocity/flow rate** key to switch to flow rate mode then enter.
5. Press **sample interval** key to display current time constant. Scroll and select time interval in order to slow down fluctuation in the readings. Enter.
6. Select log and input the logging interval desired then enter.
7. Press **setting storage option** to **ON** so that data measurements will be logged whenever sample key is turned on.
8. Take measurement by putting the probe at least 3 inches into the air stream. Press **sample** to start the sample.
9. Press **sample** to stop the sample in order to record data over time.
10. Press **next test (clear)** key to advance to the next ID. Repeat step 8 and 9.
11. To clear the last sample, press and holds key until setting is displaced from 5 - 0. Release the key at anytime before reaching zero (0) so as not to completely erase the memory.
12. To view statistics, press and hold statistics arrow and select the desired test ID. Enter.

Standard Operating Procedure (Q-track)

Standard Operating Procedures for Q-track IAQ Monitor Model 8851 Temperature, Relative Humidity, Carbon Dioxide and Carbon Monoxide

- 1.0 Press the on/off key to power the Q-track
- 2.0 If the 'service' message appears, then refer to the manual for appropriate action.
- 3.0 Make certain that the correct date and times are displayed.
- 3.1 To set the clock on the equipment, press and hold the Sample key while the Q-TRAK displays the time of day during its power-up sequence. Release the button when the Q-TRAK 'beeps'. Use the t.l. keys to change the settings, using the Sample key to store each setting and advance to the next one.
- 4.0 Slide the probe into the stand, and keep away from human contact while taking measurements, as exhaling near the probe will influence the readings.
- 5.0 When the self-check is complete, the Q-TRAK will be in 'Survey Mode', and the CO₂ (ppm), CO (ppm), Temp (OC), and Humidity (%rh) keys can be pressed to display individual readings.
- 6.0 Press the Sampling mode key to select between Surveys, LOG 1, LOG 2, and LOG 3 modes.
- 6.1 Survey mode allows for simultaneous measurements of all four parameters. Each new sample taken in this mode cancels the previous sample data.
- 6.2 LOG modes - Allows for recording of the data points for later retrieval and analysis. LOG 1 is preset to measure all four parameters. LOG 2 & 3 modes can be programmed using TRAKPRO software. Data recorded using these modes will not be erased unless the memory is cleared.
 - 6.2.1 Press the Logging Interval key while the Q-TRAK is in the LOG mode to view the logging interval which sets the averaging period for recording data in LOG 1 mode (1, 5, 15, or 30 minutes). Press and hold the Logging Interval key to change the value. The TRAKPRO software is required to change the logging interval of LOG 2 and 3.
 - 6.2.2 The Q-TRAK display is updated every second, however it is possible to display a moving average over the past 2, 5, 10, 15, or 20 seconds. Press the Time Constant key to view the current time-constant. To change the value, press and hold the key. When the desired value is displayed, immediately release the key.
- 8.0 Once the mode is selected, press the Sample key to start (or stop) data sampling.
- 9.0 Regardless of mode, pressing the Statistics key repeatedly, allows the sequential viewing of the average, minimum, and maximum readings, and can be done while the sampling is In-progress.

10.0 Press the on/off key to shut off the Q-TRAK. The memory of the Q-TRAK is erased when the power is off.

Other functions

Clearing the memory:

. One the data has been downloaded and store onto a computer using the TRAKPRO software, place the Q- TRAK into one of the three LOG modes by using the **Sampling mode** key. Press the **Clear Memory** key until the countdown reaches zero, then release quickly.

Locking the keypad to resist tampering:

. The switch is located between the probe mounting brackets, and a pointed instrument must be used to move it. With the switch in the "I" position, all keypad and display functions work. Lock the keypad after recording starts by pushing the switch to the "0" position. Remember to switch it back after sampling is complete.

Please see manual for calibration procedures.

Use the Computer Interface Cable to connect the instrument with the computer (the 25-pin to 9-pin adapter may be required). Refer to the TRAKPRO Data Analysis Software User's Manual for further details.

Standard Operating Procedure (Alnor Balometer)

1. Assemble the Balometer using the 0.608m by 0.608m frame and hood.
2. Check the Velometer for zero adjustment by placing the instrument away from any airflow, setting the range selector to the OFF position, and verify that the meter reads zero.
3. Set the range selector to the highest reading in the desired direction, supply or return.
4. Bring the Balometer into contact with the perimeter of the diffuser or grill to be measured. The velometer should be held upright with the square frame of the diffuser firmly placed inside the hood.
5. If the reading is found to be below the full scale of the next lower scale, the range selector may be switched to the next lower scale.
6. Take the airflow rate measurements in CFM. To assure maximum accuracy, the foam gasket along the top of the frame must be firmly in contact with the surface all around the opening. Take care to ensure that the body or other material is not accidentally affecting the reading by blocking or diverting the air flow at either the air entry or exit sides.

When the Balometer is carried between locations during use, detach the handle and mount it to its support plate on the base assembly. Until the Balometer is repacked in its carrying case the handle can remain mounted, whether or not it is used.

If the instrument has been stored at a temperature below 20 °C or above 30 °C it should be allowed to stabilize at room conditions in order to achieve specified accuracy.

Appendix 22 Field Log Data for Baseline Sample

(Q-Track Measurements)

S/N	School Code	Space No.	Position of Q-track	Field Data			
				CO ₂ (ppm)	CO (ppm)	T (°C)	RH %
1	R1-SE-001	12	BC	508	0	19.4	25.5
		5	FC	841	0	22.7	29.7
		4	FL	785	1	21.8	26.8
2	R1-E-002	217	BC	339	0	11.9	34.7
		219	FL	723	0	18.3	28.6
		112	BC	991	0	20.7	27.1
3	R1-NE-003	3	BC	846	0	21.4	26.1
		8	C	973	0	21.8	24.8
		6					
4	R1-NW-004	4	CL	870	0	21.5	28.1
		3	BC	843	0	20.5	30.3
		12	FR				
5	R1-E-012	171	FR	787	0	20.2	30.1
		178	BR	998	0	23.7	26.3
		179	CR	781	0	21.8	25.6
6	R2-SW-005	6	BR	895	0	20.7	23.7
		8	FR	1093	0	21	30.7
		4	FL	825	0	20	30
7	R1-SE-006	15	CL	1672	0	21.2	30.5
		20	BL	960	0	21	28.7
		27		584	0	19.5	27.4
8	R1-C-007	4	BR	587	0	23.2	23.2
		7	CL	841	0	20.6	27.7
		17	FC	1122	0	20.7	37.2
9	R2-E-021	C212	FL	1290	0	22.9	27.6
		204	FR	1149	0	24.6	27.5
		C207	BR	910	0	22.9	25.3
10	R1-NE-008	2	FL	959	1	21.9	24.3
		8	BC	1005	1	18.4	29.4
		6	FR	1022	1	22	24.4
11	R2-SE-020	15	BL	926	0	19.8	32.6
		11	FC	910	1	20.5	30
12	R1-NE-014	1	RC	1086	0	19.8	32.9
		6	FR	1035	0	20.2	32.6
		11	BC	1552	0	20.8	32.7
13	R1-NW-018	14	BL	766	1	18.8	28.4
		6	FL	598	0	21.5	26.5
		11	FL	916	1	21.9	26.8
14	R1-SE-013	421	FL	976	1	21.9	30.8
		392	FR	945	1	21.4	29.3
		327	FR	1003	1	23.4	28.8
15	R1-C-015	4	FL	829	1	23.3	27.3
		12	FL	812	1	23.2	26.3
		14	FL	718	0	21.1	27.1
16	R1-SW-017	229	FR	805	0	21.7	24.3

S/N	School Code	Space No.	Position of Q-track	Field	Data		
				CO ₂ (ppm)	CO (ppm)	T (°C)	RH %
17	R1-SW-016	221	FL	767	0	22.8	23.6
		115	FR	834	1	22.9	24.8
		108	FC	650	1	23.1	25.8
		106	FR	1026	1	24.6	25.3
		101	FC	746	0	22.3	25.9
18	R1-SW-019	6	BL	1415	1	21.2	30.6
		15	FR	1415	1	24.5	27.6
		HE	BL	898	1	23.3	29.1
19	R1-SE-011	10	FC	675	1	18.2	25.4
		17	FR	665	1	19.6	23.9
		1	BR	652	1	20.1	23.8
20	R1-E-009	108	BL	1729	0	21.8	33.7
		115	BR	1133	0	22.7	27
		HE	BL	1108	0	22.2	28.1
21	R1-C-022	205	BL	930	2	23.7	30.7
		202	CL	1888	4	23.8	30.5
		101	FL	1052	1	23	29.3
22	R1-E-010	205	FR	1397	0	20.6	36.1
		208	BC	1478	0	22.9	31.7
		203	BR	1936	1	23.4	33
23	R1-E-023	30	BR	937	0	20.5	19.7
		31	FL	1059	0	22.6	21.2
		101	FR	963	0	22.5	21.3
24	R2-NW-024	18	BR	936	0	18.1	22.2
		23	BL	1014	0	21.8	18.6
		20	BC	1859	0	22.5	17.1
25	R2-C-025	3	FR	917	0	21.6	17.9
		7	CB	1058	0	20.1	17.6
		12	CB	730	0	22.6	13.8
26	R2-SW-026	5	BL	928	0	20.3	20.2
		6	BR	1030	0	21	18.1
		3	C	580	0	20.4	15.3
27	R2-NE-027	1	CL	861	0	19.2	18.8
		11	CR	1912	1	20.4	25.3
		21	CR	1210	2	21.4	19.8
28	R2-NE-028	2	BC	1207	1	18.2	21.6
		6	BC	1136	2	20.4	19.8
		3	FL	1501	2	22.3	20.4
29	R2-SE-029	4	BL	940	23.1	19.7	1
		12	BC	1466	1	22.1	22.5
		13	BC	1821	1	22.5	23.1
30	R2-E-030	55	CL	829	0	21	23.4
		53	BC	1246	0	21.4	24.7
		13	BC	986	0	21.8	24.3
31	R2-E-031	220	FR	1022	0	19.8	27.1
		130	FR	722	0	21.4	22.3
		221	BR	843	0	21.2	24.6

S/N	School Code	Space No.	Position of Q-track	Field CO ₂ (ppm)	Data CO (ppm)	T (°C)	RH %
32	R2-E-032	7	FR	1000	1	18.1	21
		18	BC	944	0	18.6	26
		8	BC	926	0	20.5	23.6
		5	BC	933	0	20.9	22.5
33	R2-E-033	119	BC	1176	2	18.6	22.9
		110	FR	985	1	20.8	19.3
		115	FR	935	1	21.8	18.5
34	R2-NW-034	225	FC	1759	1	20.1	29.6
		128	BC	2025	1	22.7	26.3
		227	FC	1350	0	22.9	20.7
35	R2-SW-035	7	FC	862	0	20.1	16.7
		1	BL	1041	0	21.6	14.8
		10	CL	1144	0	21.4	16.1
		5	FC	1334	0	22.2	17.4
36	R2-NE-036	205	FR	860	0	20.9	16.3
		102	CL	717	0	21.8	14.7
		103	CL	659	0	20.9	14.7
37	R2-NE-037	121	BL	1108	1	21.5	22.6
		122	CR	1351	1	23	21
		235	C	1039	1	23.8	21.4
38	R2-NW-038	2	FR	648	0	18.8	20.8
		16	CR	1073	0	21.8	21.5
		17	FR	762	0	22.9	19.3
39	R2-SE-039	2	CR	899	0	18.7	20.3
		16	C	969	1	22.7	20.6
		5	CR	1295	1	22.7	20.3
40	R2-E-040	303	BC	1600	0	23.2	19.1
		301	BC	1945	0	22.3	20.2
		2	BR	1619	0	20.4	19.4
41	R2-C-041	216	FR	682	0	22.1	15.8
		212	BR	713	23.2	16	16
		106	BL	623	0	22.7	16.6
42	R2-SE-042	4	FR	804	0	18.9	20.4
		6	BC	877	0	17.2	22.5
		13	CL	1167	1	19.7	22.3
43	R2-NW-043	114	BC	1000	0	21	18.6
		107	BC	1160	0	17.6	21.4
		203	BL	1518	0	19.5	22.5

Field log Data (Air Velocity Measurements)

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
1	R1-SE-001	12	1.5	Univent	Supply	N/A	11	3
			0.1	CV	Return	N/A	23	15
		5	1.7	CV	Supply	8	N/A	N/A
			4.0	CV	Supply	8	N/A	N/A
			3.7	CV	Supply	8	N/A	N/A
			3.3	CV	Supply	8	N/A	N/A
			2.5	CV	Supply	8	N/A	N/A
			1.2	CV	Supply	8	N/A	N/A
			3.3	CV	Supply	8	N/A	N/A
			5.6	CV	Supply	8	N/A	N/A
			0.2	CV	Return	N/A	24	24
			3.8	CV	Supply	8	N/A	N/A
			4.0	CV	Supply	8	N/A	N/A
			3.2	CV	Supply	8	N/A	N/A
			3.6	CV	Supply	8	N/A	N/A
			3.7	CV	Supply	8	N/A	N/A
2	R1-E-002	217	2.9	CV	Supply	8	N/A	N/A
			3.6	CV	Supply	8	N/A	N/A
			4.9	CV	Supply	8	N/A	N/A
			0.3	CV	Return	N/A	24	24
			3.7	CV	Supply	10	N/A	N/A
			2.9	CV	Supply	10	N/A	N/A
			0.9	CV	Supply	N/A	24	3
			0.9	CV	Supply	N/A	24	3
			0.8	CV	Return	N/A	24	20
			1.7	CV	Supply	8	N/A	N/A

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
3	R1-NE-003	112	1.6	CV	Supply	8	N/A	N/A
			1.4	CV	Supply	8	N/A	N/A
			1.5	CV	Supply	8	N/A	N/A
			1.1	CV	Supply	8	N/A	N/A
			1.1	CV	Return	N/A	11	3
			1.4	CV	Supply	N/A	11	3
			0.8	CV	Return	N/A	24	12
			1.2	CV	Supply	N/A	27	7
			0.6	CV	Return	N/A	23	11
			1.9	Univent	Supply	N/A	29	6
			1.8	Univent	Return	N/A	29	6
			2.8	Univent	Supply	N/A	13	6
			0.4	Univent	Return	N/A	13	6
			3.2	Univent	Supply	N/A	25	6
			0.6	Univent	Return	N/A	29	6
4	R1-NW-004	4	0.1	Univent	Return	N/A	13	6
			0.1	Univent	Return	N/A	13	6
			3.5	CV	Supply	6	N/A	N/A
			3.0	CV	Supply	6	N/A	N/A
			3.4	CV	Supply	6	N/A	N/A
			0.4	CV	Return	6	11	11
			2.6	CV	Supply	6	N/A	N/A
			3.2	CV	Supply	6	N/A	N/A
			3.2	CV	Supply	6	N/A	N/A
			2.5	CV	Supply	6	N/A	N/A
			0.5	CV	Supply	6	N/A	N/A
			1.3	CV	Return	N/A	11	11

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
5	R1-E-012	12	3.7	CV	Supply	6	N/A	N/A
			3.9	CV	Supply	6	N/A	N/A
			2.8	CV	Supply	6	N/A	N/A
			2.9	CV	Supply	6	N/A	N/A
		171	0.4	CV	Return	N/A	11	11
			5.5	CV	Supply	10	N/A	N/A
			4.4	CV	Supply	10	N/A	N/A
			1.0	CV	Supply	10	N/A	N/A
		178	0.8	CV	Return	N/A	24	24
			3.4	CV	Supply	10	N/A	N/A
			3.4	CV	Supply	10	N/A	N/A
			4.8	CV	Supply	10	N/A	N/A
6	R2-SW-005	179	0.6	CV	Return	N/A	24	24
			4.7	CV	Supply	10	N/A	N/A
			5.1	CV	Supply	10	N/A	N/A
			4.3	CV	Supply	10	N/A	N/A
		6	0.3	CV	Return	N/A	24	24
			2.1	Univent	Supply	N/A	48	6
			0.7	Univent	Return	N/A	48	6
			0.2	Univent	Return	N/A	13	3
		8	2.2	Univent	Supply	N/A	48	6
			1.1	Univent	Return	N/A	12	3
			2.1	Univent	Supply	N/A	48	6
			1.1	Univent	Return	N/A	12	3
7	R1-SE-006	15	4.0	CV	Supply	N/A	11	6
			3.7	CV	Supply	N/A	12	6
			4.2	CV	Supply	N/A	11	6
			4.0	CV	Supply	N/A	11	6
			2.1	CV	Return	N/A	12	6

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
8	R1-C-007	20	2.1	CV	Supply	N/A	11	6
			1.8	CV	Supply	N/A	11	6
			2.8	CV	Supply	N/A	11	6
			0.0	CV	Return	N/A	12	6
		27	3.4	CV	Supply	N/A	11	6
			3.9	CV	Supply	N/A	11	6
			5.5	CV	Supply	N/A	11	6
			1.4	CV	Return	N/A	12	6
		4	2.4	Univent	Supply	N/A	48	6
			0.3	Univent	Return	N/A	84	6
			3.0	Univent	Supply	N/A	48	6
			0.5	Univent	Return	N/A	48	6
		17	2.1	Univent	Supply	N/A	48	6
			0.4	Univent	Return	N/A	84	6
			4.4	CV	Supply	8	N/A	N/A
			4.4	CV	Supply	8	N/A	N/A
9	R2-E-021	212	6.6	CV	Supply	8	N/A	N/A
			4.8	CV	Supply	8	N/A	N/A
			0.2	CV	Return	N/A	48	12
			0.0	CV	Supply	8	N/A	N/A
		204	0.0	CV	Supply	8	N/A	N/A
			0.0	CV	Supply	8	17	24
			2.7	CV	Supply	8	N/A	N/A
			2.8	CV	Supply	8	N/A	N/A
		207	2.4	CV	Supply	8	N/A	N/A
			3.8	CV	Supply	8	N/A	N/A
			1.9	CV	Return	8	N/A	N/A

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
10	R1-NE-008	2	1.0	CV	Supply	10	N/A	N/A
			3.1	CV	Supply	10	N/A	N/A
			2.3	CV	Supply	10	N/A	N/A
			1.7	CV	Supply	10	N/A	N/A
			1.8	CV	Supply	N/A	48	11
11	R2-SE-020	15	4.8	CV	Supply	10	N/A	N/A
			0.7	CV	Return	N/A	24	10
			0.6	CV	Supply	N/A	24	10
			1.5	CV	Supply	8	N/A	N/A
			1.9	CV	Supply	8	N/A	N/A
12	R1-NE-014	1	1.8	Univent	Supply	N/A	7	10
			3.0	Univent	Supply	N/A	10	10
			1.8	Univent	Supply	N/A	7	10
			0.7	Univent	Return	N/A	42	5
			0.1	Univent	Exhaust	N/A	17	12
13	R1-NW-018	6	0.7	Univent	Exhaust	N/A	17	12
			3.4	Univent	Supply	N/A	13	12
			2.3	Univent	Supply	N/A	13	12
			3.3	Univent	Supply	N/A	13	12
			1.0	Univent	Exhaust	N/A	17	12
		11	2.7	Univent	Supply	N/A	36	8
			0.3	Univent	Return	N/A	42	5
			0.7	Univent	Exhaust	N/A	17	12
			0.3	Univent	Supply	N/A	5	6
			3.2	Univent	Supply	N/A	48	6
		14	0.5	Univent	Supply	N/A	48	12
			1.0	Univent	Return	N/A	67	5
			2.4	Univent	Supply	N/A	61	6

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
14	R1-SE-013	11 421	2.7	CV	Supply	8	N/A	N/A
			5.8	CV	Supply	8	N/A	N/A
			1.1	CV	Return	N/A	12	9
			1.9	CV	Supply	N/A	61	6
			7.5	CV	Supply	8	N/A	N/A
			6.2	CV	Supply	8	N/A	N/A
			2.7	CV	Supply	8	N/A	N/A
			5.8	CV	Supply	8	N/A	N/A
			2.7	CV	Return	N/A	36	1
			3.2	CV	Supply	10	N/A	N/A
			4.4	CV	Supply	10	N/A	N/A
			4.1	CV	Supply	10	N/A	N/A
			0.3	CV	Return	10	N/A	N/A
			5.4	CV	Supply	5	N/A	N/A
15	R1-C-015	327	5.9	CV	Supply	5	N/A	N/A
			4.8	CV	Supply	5	N/A	N/A
			4.9	CV	Supply	5	N/A	N/A
			1.8	Univent	Supply	N/A	13	3
			1.2	Univent	Supply	N/A	13	3
			0.4	Univent	Return	N/A	24	12
			0.1	Univent	Supply	N/A	13	5
			0.1	Univent	Supply	N/A	13	5
			0.1	Univent	Supply	N/A	13	5
			2.6	Univent	Return	N/A	24	12

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
16	R1-SW-017	229	1.4	Univent	Supply	N/A	48	4
			1.7	Univent	Supply	N/A	48	4
		221	0.4	Univent	Return	N/A	48	12
			2.4	Univent	Supply	N/A	48	4
			0.2	Univent	Supply	N/A	48	13
			3.6	Univent	Supply	N/A	48	4
			0.4	Univent	Supply	N/A	48	13
			0.1	Univent	Return	N/A	48	13
			3.3	Univent	Supply	N/A	48	4
			0.2	Univent	Supply	N/A	48	13
			2.5	Univent	Supply	N/A	48	4
17	R1-SW-016	108	3.4	Univent	Supply	N/A	24	12
		106	2.2	Univent	Supply	N/A	24	12
		101	0.9	Univent	Return	N/A	24	24
			5.9	Univent	Supply	N/A	24	12
			2.1	Univent	Return	N/A	24	24
			2.3	Univent	Supply	N/A	49	5
		15	1.1	Univent	Return	N/A	49	5
			3.5	Univent	Supply	N/A	49	5
18	R1-SW-019	Home econ.	0.4	Univent	Return	N/A	49	4
			2.4	Univent	Supply	N/A	49	5
			0.5	Univent	Return	N/A	24	12
			4.1	Univent	Supply	N/A	37	5
		10	4.6	Univent	Supply	N/A	37	5
19	R1-SE-011	10						

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
20	R1-NW-017	213	1.3	Univent	Supply	N/A	48	4
			1.7	Univent	Supply	N/A	48	4
		200	0.8	Univent	Return	N/A	48	12
			2.9	Univent	Supply	N/A	48	4
			0.3	Univent	Supply	N/A	48	13
			3.9	Univent	Supply	N/A	48	4
			0.8	Univent	Supply	N/A	48	13
			0.4	Univent	Return	N/A	48	13
			3.7	Univent	Supply	N/A	48	4
			0.9	Univent	Supply	N/A	48	13
		325	2.6	Univent	Supply	N/A	48	4
21	R2-SW-016	111	3.4	Univent	Supply	N/A	24	12
		103	2.2	Univent	Supply	N/A	24	12
		76	0.9	Univent	Return	N/A	24	24
			5.9	Univent	Supply	N/A	24	12
			2.1	Univent	Return	N/A	24	24
			2.3	Univent	Supply	N/A	49	5
		8	1.1	Univent	Return	N/A	49	5
			3.5	Univent	Supply	N/A	49	5
22	R1-NW-019	13	0.4	Univent	Return	N/A	49	4
		45	2.4	Univent	Supply	N/A	49	4
				Univent	Supply	N/A	49	5

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
23	R1-E-023	30	1.0	CV	Supply	10	N/A	N/A
			1.9	CV	Supply	10	N/A	N/A
			1.5	CV	Supply	10	N/A	N/A
			1.7	CV	Supply	10	N/A	N/A
			1.6	CV	Supply	10	N/A	N/A
			2.0	CV	Supply	N/A	24	6
			2.2	CV	Supply	N/A	24	6
			3.2	CV	Return	N/A	24	12
			2.3	CV	Supply	N/A	12	24
			0.2	CV	Return	N/A	21	12
			2.4	CV	Supply	N/A	10	8
			4.3	CV	Supply	N/A	10	8
			0.3	CV	Return	N/A	24	8
			1.0	CV	Supply	N/A	12	12
			1.1	CV	Supply	N/A	12	12
24	R2-NW-024	18	1.2	CV	Supply	N/A	12	12
			0.1	CV	Supply	N/A	12	12
			0.6	CV	Return	N/A	24	12
			0.3	CV	Supply	N/A	12	12
			1.5	CV	Supply	N/A	12	12
		23	1.5	CV	Return	N/A	24	24
			6.7	Univent	Supply	N/A	8	3
			5.3	Univent	Supply	N/A	8	3
			5.0	Univent	Supply	N/A	8	3
			6.2	Univent	Supply	N/A	8	3
		20	4.8	Univent	Supply	N/A	8	3

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of 184- Duct	Dimension of Length (in)	Grille Width (in)
25	R2-C-025	3	6.3	Univent	Supply	N/A	7	7
			4.6	Univent	Return	N/A	7	5
			8.5	Univent	Supply	N/A	7	7
			5.7	Univent	Return	N/A	7	5
			2.4	Univent	Supply	N/A	7	7
26	R2-SW-026	12	4.6	Univent	Return	N/A	7	7
			2.8	Univent	Supply	N/A	36	6
		5	6.1	Univent	Return	N/A	24	3
			1.3	Univent	Supply	N/A	36	3
		6	1.4	Univent	Return	N/A	36	4
			2.2	Univent	Supply	N/A	36	6
		3	4.5	Univent	Supply	N/A	36	6
			4.0	Univent	Return	N/A	24	3
			2.7	Univent	Supply	N/A	25	4
			2.8	Univent	Return	N/A	24	1
27	R2-NE-027	1	1.4	CV	Supply	10	N/A	N/A
		11	0.9	CV	Supply	10	N/A	N/A
		21	1.1	CV	Supply	10	N/A	N/A
28	R2-NE-028	2	1.0	Univent	Supply	N/A	24	7
			1.9	Univent	Supply	N/A	24	7
		6	0.9	Univent	Return	N/A	37	1
			2.7	Univent	Supply	N/A	24	7
			1.0	Univent	Return	N/A	37	1
		3	3.3	Univent	Supply	N/A	24	7
			1.3	Univent	Return	N/A	37	1
			1.0	Univent	Return	N/A	37	5

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
29	R2-SE-029	4	2.5	CV	Supply	8	N/A	N/A
			2.6	CV	Supply	8	N/A	N/A
			2.9	CV	Supply	8	N/A	N/A
			2.8	CV	Supply	8	N/A	N/A
		12	1.8	CV	Return	N/A	24	24
			1.3	Univent	Supply	N/A	14	2
			1.5	Univent	Return	N/A	19	14
			1.6	Univent	Supply	N/A	14	2
		13	0.5	Univent	Return	N/A	19	14
			1.5	CV	Supply	6	N/A	N/A
			4.5	CV	Supply	6	N/A	N/A
30	R2-E-030	13	5.1	CV	Supply	6	N/A	N/A
			1.8	CV	Supply	6	N/A	N/A
			3.0	CV	Supply	6	N/A	N/A
			2.3	CV	Supply	6	N/A	N/A
		55	2.7	CV	Supply	6	N/A	N/A
			2.6	CV	Supply	6	N/A	N/A
			2.6	CV	Supply	6	N/A	N/A
			0.8	CV	Supply	6	N/A	N/A
		53	2.3	CV	Supply	6	N/A	N/A
			2.7	CV	Supply	6	N/A	N/A
			1.8	CV	Supply	6	N/A	N/A
			2.8	CV	Supply	6	N/A	N/A
			2.1	CV	Supply	6	N/A	N/A

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
31	R2-E-031	220	3.1	CV	Supply	6	N/A	N/A
			0.9	CV	Return	6	N/A	N/A
			1.8	CV	Supply	10	N/A	N/A
			1.3	CV	Supply	10	N/A	N/A
			1.9	CV	Supply	10	N/A	N/A
		221	1.5	CV	Supply	10	N/A	N/A
			0.7	CV	Return	N/A	48	36
			2.3	CV	Supply	10	N/A	N/A
			3.6	CV	Supply	10	N/A	N/A
			1.9	CV	Supply	10	N/A	N/A
32	R2-E-032	130	2.2	CV	Supply	10	N/A	N/A
			1.0	CV	Return	N/A	48	36
			5.8	CV	Supply	10	N/A	N/A
			5.5	CV	Supply	10	N/A	N/A
			5.3	CV	Supply	10	N/A	N/A
		18	6.3	CV	Supply	10	N/A	N/A
			0.8	CV	Return	N/A	24	4
			8.0	CV	Supply	N/A	12	1
			6.1	CV	Supply	N/A	12	1
			7.4	CV	Supply	N/A	12	1
		8	3.4	CV	Supply	N/A	12	1
			1.8	CV	Supply	N/A	12	1
			0.9	CV	Supply	N/A	12	1
			1.0	CV	Supply	N/A	12	1
			2.9	CV	Supply	N/A	12	1
		5	1.1	CV	Supply	N/A	12	1
			0.2	CV	Supply	N/A	24	12

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
33	R2-E-033	119	0.4	CV	Supply	N/A	24	12
			0.7	CV	Supply	N/A	24	12
			1.7	CV	Supply	N/A	17	12
			3.5	CV	Supply	N/A	17	2
			1.2	CV	Supply	N/A	17	2
		115	1.1	CV	Supply	8	N/A	N/A
			1.6	CV	Supply	8	N/A	N/A
			1.3	CV	Supply	8	N/A	N/A
			1.6	CV	Supply	8	N/A	N/A
			2.6	CV	Supply	N/A	24	3
34	R2-NW-034	110	3.3	CV	Supply	N/A	24	3
			2.9	CV	Supply	N/A	24	3
			1.1	CV	Exhaust	N/A	48	8
			0.6	CV	Supply	N/A	6	24
			0.0	CV	Supply	N/A	6	24
		225	0.2	CV	Exhaust	N/A	N/A	N/A
			2.1	CV	Supply	N/A	6	24
			1.9	CV	Supply	N/A	6	24
			0.2	CV	Exhaust	N/A	N/A	N/A
			0.2	CV	Supply	N/A	6	24
35	R2-SW-035	128	0.1	CV	Supply	N/A	6	24
			1.4	CV	Exhaust	N/A	N/A	N/A
			2.9	Univent	Supply	N/A	48	6
			0.8	Univent	Return	N/A	12	6
			0.6	Univent	Return	N/A	48	4
		5	2.1	Univent	Supply	N/A	48	6
			1.1	Univent	Return	N/A	12	6
			1.0	Univent	Return	N/A	48	6

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
36	R2-NE-036	205	1.8	Univent	Supply	N/A	48	6
			0.8	Univent	Return	N/A	48	6
			0.1	Univent	Return	N/A	12	6
			2.3	CV	Supply	N/A	24	1
			4.4	CV	Supply	10	N/A	N/A
37	R2-NE-037	103	3.0	CV	Supply	10	N/A	N/A
			1.7	Univent	Supply	N/A	13	9
			0.3	Univent	Return	N/A	12	2
			1.4	Univent	Return	N/A	37	5
			3.0	Univent	Supply	N/A	24	9
38	R2-NW-038	235	1.0	Univent	Return	N/A	37	5
			0.5	Univent	Return	N/A	24	9
			0.7	Univent	Supply	N/A	36	6
			0.1	Univent	Return	N/A	72	5
			0.0	Univent	Return	N/A	13	12
39	R2-SE-039	2	0.4	CV	Supply	N/A	24	5
			0.1	CV	Supply	N/A	48	5
			0.3	CV	Supply	N/A	24	5
			2.8	CV	Supply	N/A	10	3
			1.4	CV	Supply	N/A	11	3
39	R2-SE-039	17	2.2	CV	Return	N/A	9	10
			2.0	CV	Supply	N/A	11	3
			1.8	CV	Return	N/A	10	9
			2.7	CV	Supply	N/A	11	2
			1.5	CV	Return	N/A	12	13
39	R2-SE-039	5	0.2	CV	Return	N/A	10	15
			1.9	CV	Supply	N/A	11	2
			2.6	CV	Return	N/A	12	13

S/N	School	Class no	Ave. Vel m/s	Vent. Type	Supply/ Return	Diameter of Duct	Dimension of Length (in)	Grille Width (in)
40	R2-E-040	301	0.8	CV	Return	N/A	24	24
			4.6	CV	Supply	N/A	12	3
			3.9	CV	Supply	N/A	12	3
			8.0	CV	Supply	N/A	12	3
			1.9	CV	Return	N/A	25	5
		303	2.9	CV	Supply	N/A	12	3
			6.2	CV	Supply	N/A	12	3
			6.1	CV	Supply	N/A	12	3
			1.2	CV	Return	N/A	25	5
			0.1	CV	Supply	N/A	96	1
41	R2-C-041	2	0.5	CV	Supply	N/A	96	1
			0.2	CV	Supply	N/A	96	1
			0.8	CV	Supply	N/A	96	1
			0.5	CV	Supply	N/A	96	1
			0.4	CV	Supply	N/A	96	1
		212	0.3	CV	Return	N/A	48	24
			1.1	CV	Supply	N/A	13	36
			1.1	CV	Return	N/A	13	36
			2.2	CV	Supply	N/A	13	36
			1.6	CV	Supply	N/A	13	36
42	R2-SE-042	4	1.2	CV	Return	N/A	24	13
			2.3	CV	Supply	N/A	12	3
			1.5	CV	Return	N/A	24	12
			3.2	CV	Supply	N/A	12	3
			1.4	CV	Return	N/A	24	12
		6	3.4	CV	Supply	N/A	12	3
			1.0	CV	Return	N/A	24	12
43	R2-NW-043	No air vents in selected spaces						

Appendix 23**Regression Analysis for Correction of Air Velocity Results**

A linear regression analysis was performed in order to correct all calculated airflow rates obtained from the Velocicalc Plus Airflow Meter. Seventeen 0.608 m by 0.608 m diffusers were randomly selected. The Velocicalc Plus Air Meter was used to take air velocity measurements from the seventeen diffusers. Airflow rates were then calculated by multiplying air velocities by the duct areas. Airflow rates were also taken from each diffuser with the Alnor Blometer Air Balancing Instrument. The results of calculated airflow rates when the Velocicalc Plus Air Meter was used and airflow rates when the Alnor Balometer was used are provided in the table below:

Full data set for Linear model $Y = 0.55X + 167$ ($R^2 = 0.47$)	
Velocicalc (X)	Alnor (Y)
314	246
251	246
314	263
281	272
325	289
436	297
197	306
415	306
329	400
186	357
871	493
809	518
871	544
809	552
422	578
526	603
773	1003

Both data sets provided above were used to perform a regression analysis using excel spreadsheet. The linear regression model obtained was applied in correcting all calculated airflow rates obtained with the Velocicalc Plus Air Meter.

Regression Model

$$Y = \beta + \beta_0 X$$

Y = Airflow rates from Alnor Balometer

X = Calculated airflow rates = (duct area x air velocity)

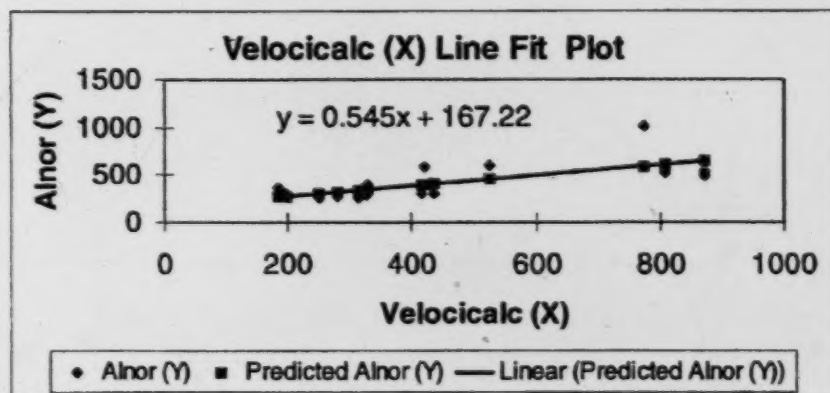
β = Intercept on the regression model

β_0 = Correction factor

From the line fit plot, the regression model is $Y = 159 + 0.55$

Model Summary

Regression Statistics	
Multiple R	0.7
R square	0.47
Adjusted R	0.43
Standard Error	146
Observations	17



Appendix 24**Statistical Analysis**

Statistical Analysis indicating Significant Differences in CO₂ Concentration from different Locations with Spaces.

t-test at a significant level of 0.05 was performed for the results of CO₂ concentrations in Category "A" spaces (CO₂ concentrations in the Front greater than Back). The results indicating any significant differences is provided below:

Comparison of CO₂ concentrations in Category "A" Spaces.

	Back	Front
Mean	1581.4	1830.6
Variance	296031.8	163810.8
Observations	5	5
Pearson Correlation	0.95	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2.75	
P(T<=t) one-tail	0.03	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.05	
t Critical two-tail	2.77	

t-test at a significant level of 0.05 was performed for the results of CO₂ concentrations in Category "B" spaces (CO₂ concentrations in the Back greater than Front). The results indicating any significant differences is provided below:

Comparison of CO₂ concentrations in Category "B" Spaces

	Back	Front
Mean	1818.7	1507.2
Variance	249031.6	70845.5
Observations	7	7
Pearson Correlation	0.87	
Hypothesized Mean Difference	0	
Df	6	
t Stat	2.77	
P(T<=t) one-tail	0.01	
t Critical one-tail	1.94	
P(T<=t) two-tail	0.03	
t Critical two-tail	2.44	

Statistical Hypothesis Testing for Variances

F-test at a significant level of 0.05 was performed for the results of CO₂ concentrations in Category "A" spaces (CO₂ concentrations in the Front greater than Back). The results showing any variance between the back and Front locations is provided below:

Comparison of variance between the Back and the Front CO₂ concentrations in Category "A" Spaces.

	Back	Front
Mean	1581.4	1830.6
Variance	296031.8	164810.8
Observations	5	5
df	4	4
F	1.79	
P(F<=f) one-tail	0.29	
F Critical one-tail	6.38	

F-test at a significant level of 0.05 was performed for the results of CO₂ concentrations in Category "B" spaces (CO₂ concentrations in the Back greater than Front). The results showing any variance between the back and Front locations is provided below:

Comparison of variance between the Back and the Front CO₂ concentrations in Category "B" Spaces.

	Back	Front
Mean	1818.714	1507.2
Variance	249031.6	70845.5
Observations	7	7
df	6	6
F	3.5	
P(F<=f) one-tail	0.07	
F Critical one-tail	4.28	

Appendix 25

CO₂ Decay

CO₂ decay method was used to obtain air exchange rates. The results of CO₂ depletion of five spaces obtained from three hours after students have left the randomly selected classes at the end of a school day is provided in the table below:

Time	CO ₂ Decay by Space X 1000 (mg/m ³)				
	R2-SE-029	R2-SE-020	R1-SE-011	R2-NE-027	*R2-NE-023
0	741	1854	726	1104	372
0.25	704	1371	699	1103	370
0.5	668	1068	632	964	368
0.75	645	928	586	867	368
1	633	839	545	777	370
1.25	612	757	520	753	370
1.5	597	705	497	724	370
1.75	589	689	480	742	369
2	568	693	466	713	369
2.25	565	696	454	714	370
2.5	565	700	445	615	367

*Was excluded from the decay plot.

R2 Round two

R1 Round one

SE South East

NE North East

In order to obtain the CO₂ decay of each of the selected spaces, it was ensured that windows and doors were closed and the ventilation system was still operational through out the three hours of sampling. When the rate of CO₂ production in the selected spaces is Zero, Space concentration will decay to the outdoor concentration according to the equation:

$$C_t = C_o \exp(-xt / v)$$

$$\ln \frac{C_t}{C_o} = -\frac{xt}{v}$$

$$\frac{xt}{v} = \ln C_t - \ln C_o$$

$$N = \frac{x}{v} = \frac{\ln C_t - \ln C_o}{t}$$

Where

N = air exchange rate

X = airflow rate leaving the space, m^3/hr

V = space volume, m^3

C_t = CO₂ concentration after time t, mg/m^3

C_o = Initial CO₂ concentration, mg/m^3

T = time, hr